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THE UNIVERSITY OF ALBERTA

OPERATIONAL MODIFICATIONS TO AN ACTIVATED SLUDGE PROCESS

BY

DAVID R. SPINK, B.Sc.

©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
AND RESEARCH IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

FALL, 1975

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled OPERATIONAL MODIFICATIONS TO AN ACTIVATED SLUDGE PROCESS submitted by DAVID ROY SPINK in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

A study of secondary treatment operation at the Edmonton Sewage Treatment Plant was undertaken June through September 1974. The plant uses the activated sludge process for secondary treatment, and the objective of this thesis was to examine aspects of secondary operation. Emphasis was placed on using procedures and controls that were amenable with existing plant facilities and design. The three areas of study undertaken involved; 1) an hydraulic procedure for controlling the solids concentration within the system, 2) an examination of the reactivation times used at the plant, and 3)an attempt to enhance bioflocculation.

The maintenance of a fixed food to micro-organism ratio by hydraulic control resulted in increased efficiencies.

The 4-4.8 hours minimum reaeration required by the physical design of the plant appears to be excessive. Oxygen uptakes showed that reactivation times of 2-3 hours were desirable but the conclusion drawn was that with present operating procedure and aeration equipment

reactivation times of 4-4.8 hours were not excessive.

In an attempt to enhance bioflocculation and final sedimentation of solids aeration rates were controlled in the final pass of a section. No improvement in the settleability of the sludge was observed within the range of aeration variations.

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OPERATIONAL MODIFICATIONS TO AN ACTIVATED SLUDGE PROCESS

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LIST OF SYMBOLS

BOD	biochemical oxygen demand
COD	chemical oxygen demand
DO	dissolved oxygen
F:M	food to microorganism
g.d	gallons per day
Kd	endogenous respiration rate
MCFD	million cubic feet per day
MCRT	mean cell residence time
MIGD	million imperial gallons per day
mg/l	milligrams per liter
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
Q	flow
RSSS	return sludge suspended solids
RSTS	return sludge total solids
SS	suspended solids
SVI	sludge volume index
TOC	total organic carbon
TS	total solids
U	food to microorganism ratio
VSS	volatile suspended solids
X	mass of solids in the system
Y	growth rate coefficient
θ_c	mean cell residence time

CHAPTER I

INTRODUCTION

1.1 General

The complex processes involved in the breakdown of organic material in the activated sludge system are the combination of several basic physical and biological processes interacting both independently and dependently. To better understand and control such a complex system requires that the basic processes, upon which the complex system is built, are quantitatively understood.

The activated sludge system can be described in its entirety by the following four processes or reactions *(Kalinske, 1971)*:

1. Basic respiration and metabolism of aerobic cells.
2. Mass transfer of nutrients, in the substrate and dissolved oxygen (D.O.) to the cell surface and removal of metabolic waste products.
3. Mass transfer of oxygen from the atmosphere or aeration source into the waste liquid.
4. Aggregation or flocculation of individual microorganisms into masses that can be removed by sedimentation.

Of the four processes, only the third does not involve the microbial system. To fully realize the potential of activated sludge treatment it is necessary to develop controls that relate the operation of the treatment system to these four basic processes.

1.2 The Scope and Purpose of The Investigation

The purpose of this study was to improve the treatment efficiency of the activated sludge process used by the Edmonton Sewage Treatment Plant, by utilizing controls that related directly to the basic processes outlined in section 1.1. To achieve this objective an examination of the existing process was necessary and after examining both the physical structure of the secondary treatment sections and the operational controls being used, three areas for possible improvement were found. The three areas were:

1. Solids control in the process,
2. Sludge reaeration or reactivation, and
3. Bioflocculation.

The method of solids control used at the Edmonton plant did not allow for variations in daily loading and it was felt that more recently developed controls, based on microbial kinetics, could be applied to give a more effective operating method.

Sludge reaeration time at the plant was fixed at a minimum of four hours, due to the physical layout of the secondary sections and at normal return sludge rates this reaeration time is approximately 4.8 hours. Based on present operation of the secondary sections and literature studies it appeared that reaeration periods of this duration were longer than necessary. The second area of this study involved examining the reaeration period to determine if it was excessive and to make modifications if possible.

The settleability of the aerated sludge at the Edmonton facility is often poor and the existence of butterfly valves to control aeration rates in the last part of the aeration tank provided an opportunity to attempt to improve bioflocculation by varying dissolved oxygen concentrations.

By varying or changing the operation of the activated sludge process in these three areas it was hoped that significant improvements in the treatment efficiencies at the Edmonton plant could be realized.

To measure treatment improvements, removal efficiencies using existing controls were compared to those obtained using a control based on biological growth. Oxygen uptake rates, dissolved oxygen profiles and total solids values were collected for the reaeration tank under normal operating conditions and with recycling to determine if a shorter reaeration time was desirable. Dissolved oxygen profiles and settled volumes were obtained and removal efficiencies were studied for a treatment section with controlled aeration rates in the last aeration pass to determine if bioflocculation could be enhanced and if so, were improved efficiencies obtained.

1.3 Limitations of the Research

In an activated sludge process such as the one at the Edmonton Sewage Treatment Plant, there are numerous physical, chemical and biological variables that in one way or another affect the efficiency of the process. Many of the physical variables are measured and to some extent controlled but chemical and biological variables are more difficult to measure and the only control exercised over these variables results through control of the physical variables. Some of the physical variables controlled at the Edmonton plant are: flow rates, return sludge rates, waste sludge rates, influent flow patterns, aeration rates and detention times.

The following problems arise in plant studies. Flow rates can vary significantly on an hourly, daily and on a monthly or seasonal basis. Flow rates are difficult to measure. The return and waste sludge rates which determine the weight of solids maintained within the system can be determined fairly accurately at the Edmonton plant. Influent flow (contacting) patterns are often changed at the plant but these changes are not recorded or considered significant by operating personnel. Aeration rates at the Edmonton plant are controlled on the basis of a single dissolved oxygen reading in each section. Detention times depend on flow rates, return sludge rates and contacting patterns. The usefulness of many of these controls is limited due to difficulties in accurately controlling and measuring them.

Solids and BOD calculations are based on 24 hour composite samples which are not composited on a basis proportional to flow. Most of the data used in the operation and control of the Edmonton plant consists of daily averages.

To cope with the large number of variables and unknowns, encountered during this study, values obtained during the various tests were compared to those from other sections operating over the same period. Although this procedure gives information only useful for operating conditions similar to those during the study procedure it can be assumed that average operating data collected over a relatively long period will be quite representative of normal conditions provided no unusual factors exist (eg. spring runoff).

1.4 Organization

In Chapter II a brief description of overall plant operation, an indepth discussion of the physical layout and operation of the activated sludge process is given. Chapter III contains the study on the operation of an activated sludge process using a growth rate control. Literature review, study procedure, data and conclusions are presented in this Chapter. Similarly, Chapters IV and V contain the complete units of study on sludge reaeration and bioflocculation respectively.

1.5 Reference

Kalinske, A. A. 1971 "Effect of Dissolved Oxygen and Substrate Concentration on the Uptake of Microbial Suspensions" JWPCF, v.43, p.73.

CHAPTER II

THE EDMONTON SEWAGE TREATMENT PLANT

2.1 Description of the Edmonton Sewage Treatment Plant

2.1.1 General

The Edmonton Sewage Treatment Plant is located on 50th Street and the south bank of the North Saskatchewan River. Placed in operation in 1956 the Plant was designed to provide primary treatment for a flow of 50 MIGD and secondary treatment for a flow of 25 MIGD. Additions to the facility have increased the plant design capacity to 109 MIGD for primary treatment and 45 MIGD for secondary treatment. Present 1974 plant size is shown in FIGURE 1.

Approximately 90% of the City sewage flow is handled at the plant. This flow includes domestic and industrial discharges plus storm water from districts which are still served by combined sewers. The remaining 10% of the flow, largely from the City's three biggest packing houses and the Beverly and Oliver subdivisions, is treated at the Clover Bar Industrial lagoons.

2.1.2 Treatment Processes

Primary treatment of wastewater at the Edmonton

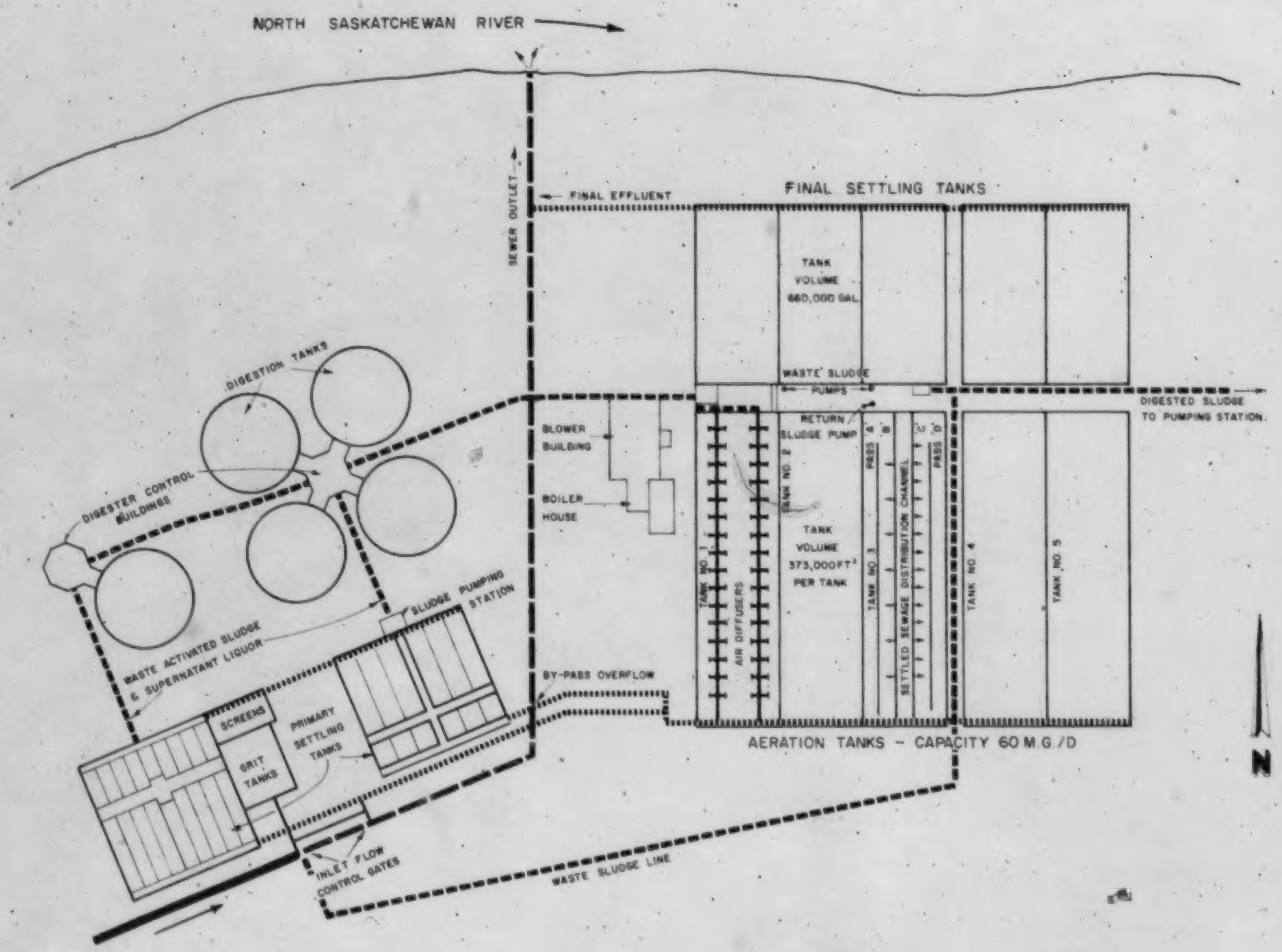
NORTH SASKATCHEWAN RIVER
SEWER OUTLET
FINAL EFFLUENT
FINAL SETTLING TANKS
TANK
VOLUME
660,000 GAL.
WASTE SLUDGE
PUMPS
RETURN
SLUDGE PUMP
DIGESTED SLUDGE
TO PUMPING STATION.
BLOWER
BUILDING
BOILER
HOUSE
TANK NO. 1
AIR DIFFUSERS
TANK NO. 2
TANK
VOLUME
373,000FT³
PER TANK
PASS 'A'
'B'
TANK NO. 3
SETTLED SEWAGE DISTRIBUTION CHANNEL
'C'
PASS 'D'
TANK NO. 4
TANK NO. 5
AERATION TANKS - CAPACITY 60 M.G./D
N
DIGESTION TANKS
DIGESTER CONTROL
BUILDINGS
WASTE ACTIVATED SLUDGE
& SUPERNATANT LIQUOR
SLUDGE PUMPING
STATION
BY-PASS OVERFLOW
SCREENS
GRIT
TANKS
PRIMARY
SETTLING
TANKS
INLET FLOW
CONTROL GATES
WASTE SLUDGE LINE

FIGURE 1: CITY OF EDMONTON - MAIN WASTE WATER TREATMENT PLANT

plant consists of grit removal, screening and primary settling. The solids removed in the primary settling tanks are treated in anaerobic digestors. Secondary treatment of effluent from the primary settling tanks, is provided by a biological treatment process.

Wastewater entering the Edmonton plant is divided into three equal streams which flow through grit tanks, operating in parallel. Detention time in the grit tanks is approximately five minutes. During this period the wastewater is aerated vigorously. This allows heavy sand and silt to settle but the organics remain in suspension due to the mixing action. Following the grit tanks are screens, which remove rags, papers and larger wastes. The flow then enters the primary settling tanks.

Four primary settling tanks, giving detention periods of one to two hours at normal flows, remove settleable organics. The solids that settle are collected by scrapers into a hopper from which they are pumped into one of the five anaerobic digestors. Scum from the top of the primary settling tanks is also pumped to the anaerobic digestors.

In the anaerobic digestors, breakdown of the solids from the primary settling tanks occurs through a process known as anaerobic decomposition. The temperature of the digestors is carefully controlled at an optimum level for microbial activity and mixing is provided by recycling sludge and compressed gas bubbling. Gas from the digestors is used to heat the plant and the excess is flared. Digested solids from the digestors are pumped to permanent storage lagoons east of the City.

The effluent from the primary settling tanks flows to the secondary, biological treatment sections, which use a process called activated sludge. The secondary influent enters one of the five identical secondary sections and is mixed with recycled, reactivated sludge. This mixture undergoes aeration for two to four hours and then flows into the final settling tanks. Effluent from these tanks is discharged to the river while the solids that settle out are recycled and reactivated (reaerated). Excess solids which must be removed from the secondary section are pumped back to be mixed with the primary influent, and are removed to the digestors along with the primary sludge.

2.2 Activated Sludge

2.2.1 General

The activated sludge process was developed in

England in 1913 by Ardern and Lockett *(McKinney, 1962)*. The process is purely a biological one, based on aerobic oxidation principles. The many variations that exist in the design and operation of activated sludge processes and its widespread use testify to its usefulness and flexibility *(Fair et al, 1968)*.

2.2.2 Theory of Operation

In an activated sludge process biological flocs are mixed with liquid wastes under aerobic conditions. The removal of the organics from the wastewater can be considered as a two phase process. The first phase is one of high initial removals and can be attributed to one or more of the following mechanisms *(Eckenfelder, 1966)*:

1. Enmeshment of suspended matter ($>10^{-3}$ mm dia) in the biological floc.
2. Adsorption on the biological floc of colloidal material ($>10^{-6}$ mm dia)
3. Biosorption of soluble organic matter ($<10^{-6}$ mm dia) by the micro-organisms.

The second phase, following the high initial removal by these three mechanisms, involves the slower removal of the remaining soluble BOD.

This mixture of micro-organisms, organic matter and inorganic matter is mixed and aerated until the organisms have utilized most of the available organics. During this period there is an increase in the number of organisms and the amount of biological floc. After sufficient aeration and mixing, flow enters settling tanks. Effluent from these tanks is usually discharged to a receiving body of water and the solids that settle are pumped back to the aeration basin and used as the biological floc. This recycle of solids is continuous. To compensate for the increase in solids, that occurs due to microbial growth, a small portion of the sludge is wasted from the system continually.

Many variations of the activated sludge process exist and a brief description of some of these will be helpful in understanding Edmonton's process.

2.2.3 Activated Sludge Processes

The three most commonly used activated sludge processes are:

1. Conventional and modified
2. Step aeration, and
3. Contact stabilization

The conventional and modified processes are shown in FIGURE 2(A). In the conventional process return sludge is mixed with wastewater in the aeration tank for a period of four to eight hours. The process is capable of producing BOD reductions of 90% to 95%. The modified process is similar to the conventional one except a shortened aeration period is used with a reduced quantity of suspended solids in the mixed liquor. The modified process does not give as high a degree of purification as the conventional process but aeration requirements and tank sizes are reduced.

Step aeration involves adding wastewater uniformly or in steps along the length of an otherwise conventional aeration tank (FIGURE 2(B)). The advantages of the step aeration process are:

1. A more uniform oxygen demand resulting in better oxygen utilization
2. The introduction of sewage in steps helps to maintain an activated sludge with good adsorptive characteristics and therefore a shorter aeration period is required
3. Effects of fluctuations in influent and floc quality are reduced.

Removal efficiencies in the range of 90% have been achieved using step aeration *(Rich, 1963)*

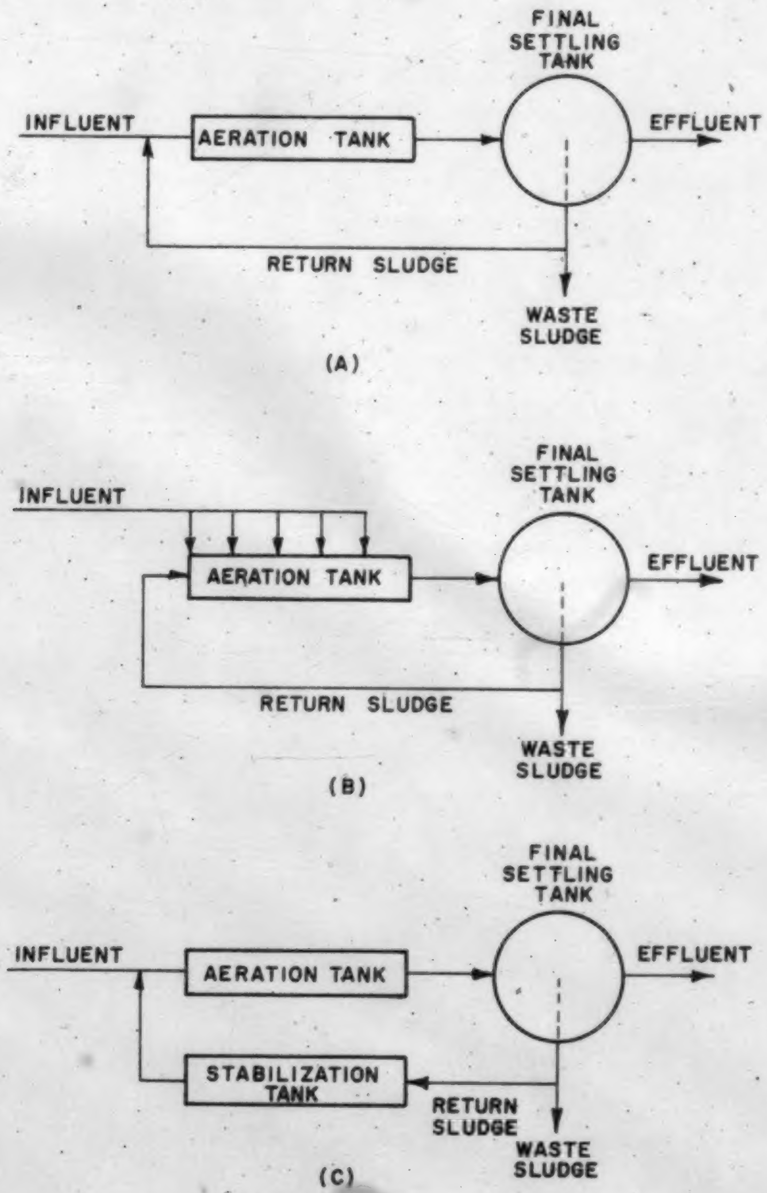
FINAL SETTLING TANK
INFLUENT
AERATION TANK
EFFLUENT
RETURN SLUDGE
WASTE SLUDGE
(A)
FINAL SETTLING TANK
INFLUENT
AERATION TANK
EFFLUENT
RETURN SLUDGE
WASTE SLUDGE
(B)
FINAL SETTLING TANK
INFLUENT
AERATION TANK
EFFLUENT
STABILIZATION TANK
RETURN SLUDGE
WASTE SLUDGE
(C)

FIGURE 2 : SOME SCHEMATIC DIAGRAMS OF THE ACTIVATED SLUDGE PROCESS;(A) CONVENTIONAL PROCESS B) STEP AERATION,(C) CONTACT STABILIZATION

Contact stabilization processes make use of the high initial removal rates of activated sludge to reduce aeration basin size. In this process wastewater and activated sludge are contacted for a short period in the aeration tank. The sludge settled in the settling tanks is then aerated vigorously in the reaeration basin. During this reaeration period the organic material adsorbed by the biological flocs is used as the energy source for cell growth and metabolism. If the reaeration time is just sufficient to restore the adsorptive characteristics of the sludge,the process is called contact stabilization (FIGURE 2(C)). If reaeration periods are in excess of those required for 'reactivation' the process is called extended aeration. The extended aeration process reduces sludge volumes handled by the anaerobic digestors because solids are reduced aerobically in the reaeration basin. The only difference between the extended aeration and the contact stabilization processes is the period of sludge reaeration. In the contact stabilization process, too short a period results in deoxygenation and loss of sludge activity and too long a reaeration period will cause loss of sludge clarifying power and partial floc disintegration. Care must be taken in the operation of the contact stabilization process to ensure that reaeration periods are not so long as to give a form of the extended aeration process.

The main advantage of sludge reaeration is that the combined volume of aeration and sludge reaeration tanks, required to maintain a certain BOD-to-solids loading and mixed liquor concentration is less than the aeration volume required in the conventional process to maintain the same loadings. When sludge reaeration is used to reactivate the biological floc, as in the contact stabilization process, it is desirable to add some food, or nutrients to the reaeration tank. Sludge reaeration processes are used in treatment of high BOD wastes and are particularly useful in treating wastes which are high in colloidal and suspended BOD. Removal efficiencies are lower than for the conventional and step aeration processes. BOD reductions of 80% to 85% can be expected *(Metcalf and Eddy, 1972)*.

The activated sludge process used by the City of Edmonton Sewage Treatment Plant incorporates step aeration and sludge reaeration.

2.3 The Edmonton Activated Sludge Process

2.3.1 Design of the Process

Secondary treatment is provided at the Edmonton plant, by five identical activated sludge sections operating in parallel. Each section is operated independently of the other four but all receive effluent from the primary settling tanks. FIGURE 3 shows a schematic representation of a treatment section. FIGURE 1 shows a

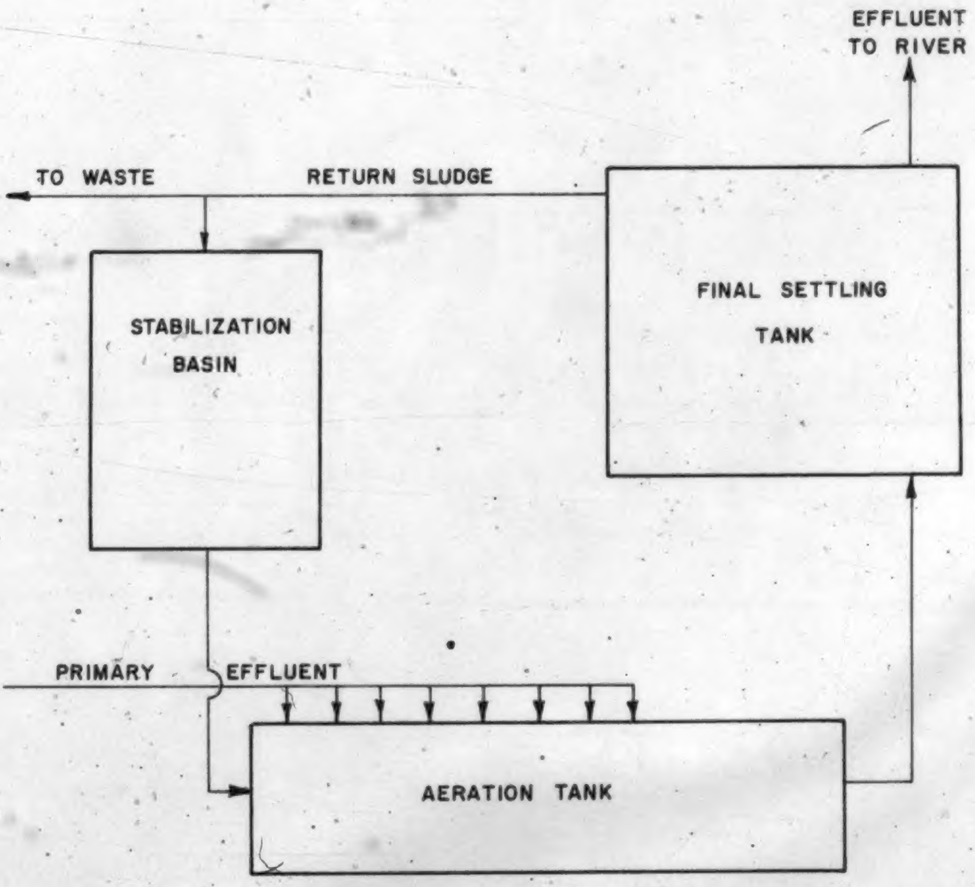
EFFLUENT
TO RIVER
TO WASTE
RETURN SLUDGE
STABILIZATION
BASIN
FINAL SETTLING
TANK
PRIMARY
EFFLUENT
AERATION TANK

FIGURE 3: SCHEMATIC DIAGRAM OF THE EDMONTON ACTIVATED SLUDGE PROCESS

plan view of the secondary sections with location of air diffusers and sewage distribution channels given.

The aeration tanks, which are 20 feet wide and 15 feet deep have numerous inlets along the 2nd and 3rd passes to allow for step aeration (FIGURE 4 & 5). Each of the five aeration sections contains four passes each 310 feet in length, with round-the end flow. The air is supplied by two main air headers between the first and second and third and fourth passes, with sparger-type air diffusers along the bottom of each pass (FIGURE 5).

The arrangement of gates in the aeration tank are such that a minimum sludge reaeration volume of 93,000 cu.ft (pass 1 volume) must be used. This volume can be increased if inlet gates along the beginning of pass 2 are closed. Inlet patterns (contact patterns) can be changed by varying the combinations of the open gates.

After the 4th pass flow enters the final settling tanks. These final settling tanks are rectangular, (155 feet long and 80 feet wide) with a volume of 660,000 gallons. There are 4 overflow throughs in each tank providing 640 feet of weir length. Effluent from the tanks is discharged to the river. Sludge is collected at the north (far) end of the tanks by longitudinal conveyors. This sludge is pumped back to the beginning of pass 1 by pumps having a capacity of 3.5 MIGD. From this return line, waste sludge is also pumped to a maximum of .4 MIGD.

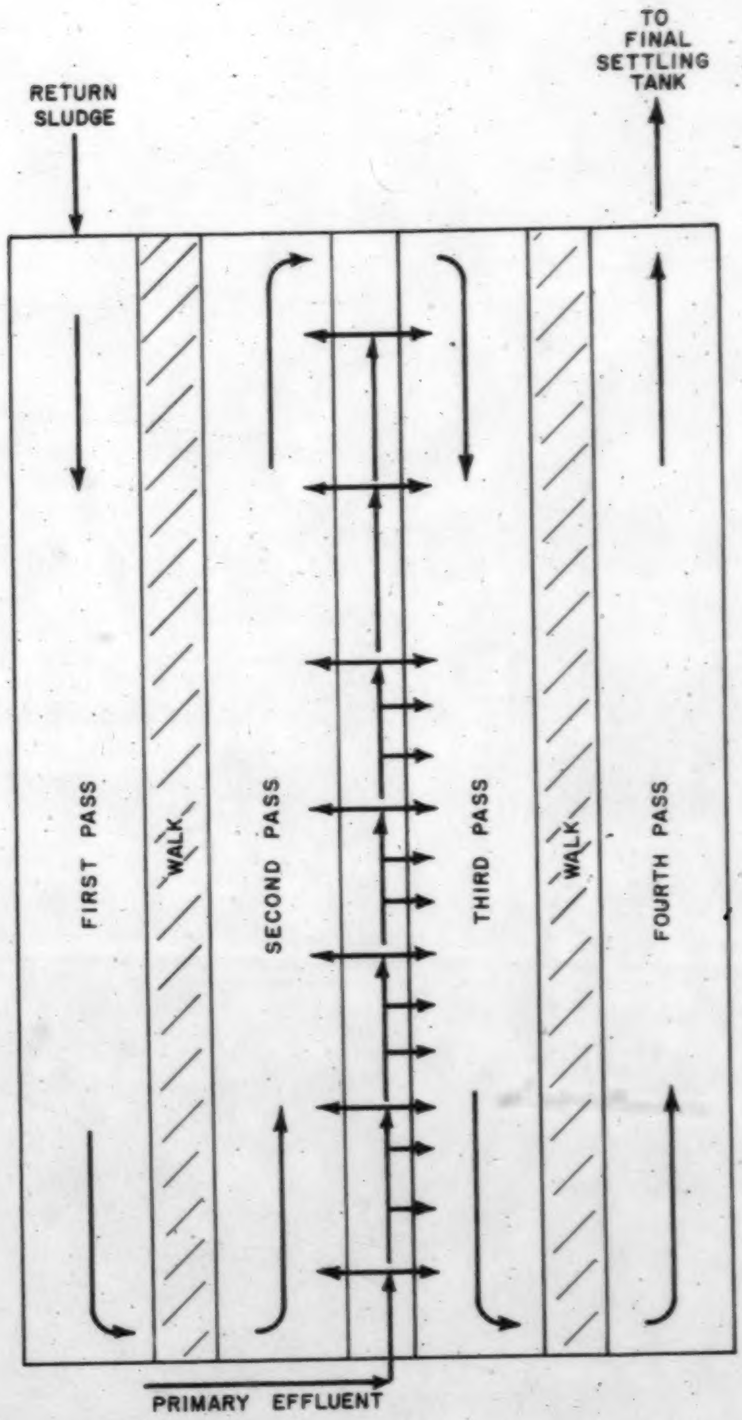
RETURN SLUDGE
TO FINAL SETTLING TANK
FIRST PASS
WALK
SECOND PASS
THIRD PASS
WALK
FOURTH PASS
PRIMARY EFFLUENT

FIGURE 4: AERATION TANK AND INFLUENT DISTRIBUTION PATTERN

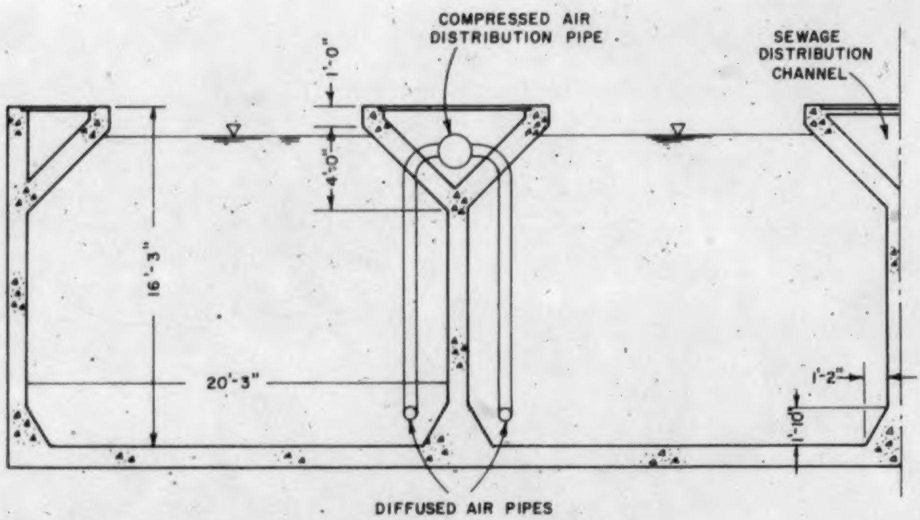
COMPRESSED AIR DISTRIBUTION PIPE
SEWAGE DISTRIBUTION CHANNEL
1'-0"
4'-0"
16'-3"
20'-3"
1'-2"
1'-10"
DIFFUSED AIR PIPES

FIGURE 5: HALF SECTION OF AN AERATION TANK, EDMONTON SEWAGE TREATMENT PLANT

The design of the activated sludge process, used at Edmonton, is such that wide ranges in operation are afforded.

2.3.2 Operation of the Process

Waste flow to the secondary treatment sections is controlled by two bypass weirs. Controls are such that flow rates to the secondary sections are recorded continuously and can be controlled from a central control room. Flow rates for each of the secondary sections are calculated by multiplying the total secondary flow and the number of gates open in the particular section, then dividing this by the total number of gates open in all five sections

Example calculation:

flow to secondary - 30 MIGD

number of gates open section 1 - 22 (all open)

number of gates open all five section - 100

flow to section 1 - $30 \times \frac{22}{100} = 6.6$ MIGD

This procedure is very empirical and of questionable applicability when the number of gates open in any section is less than 15. Secondary flows are usually controlled at a maximum rate of 45 - 65 MIGD. Flow values usually range from 20 - 25 MIGD during early morning to 50 - 65 MIGD for afternoon and evening flows. Organic loads to the secondary vary from 50 - 400 mg/l suspended solids and 50 - 200 mg/l BOD with average daily values for both between 100 - 200 mg/l.

Primary effluent is introduced through inlets along the 2nd and 3rd passes of the aeration tanks. This has not always been the operating procedure. Prior to 1974 the sewage was added along the end of the 3rd pass only, giving contact stabilization treatment. This form of treatment was discontinued when it was found that greater treatment efficiencies could be obtained using the present operating procedure.

If organic or hydraulic loadings to a section are too high (i.e. treatment efficiencies fall below an acceptable level) gates are closed along the two passes. Gates are added in such a way as to give uniform distribution of sewage along both passes.

The opening or closing of inlet gates, to control the waste flow to a section, presents a difficulty. Once the secondary flow is set, using the bypass weirs, this amount of flow must be handled by the secondary. If, therefore, some gates in a particular section are added to reduce the flow into that section, then the flow to the other sections will increase. To reduce or increase flow to an individual section and maintain the same flows in the other sections involves changing gate openings as well as bypass weir settings.

The amount of air required to maintain sufficient dissolved oxygen concentrations is determined using a DO probe located at the end of the 4th pass. Residuals of between 1 and 2 mg/l are maintained by adjusting air flows through the main headers. Three problems exist regarding aeration at the Edmonton plant. They are;

1. Controlling aeration rates for each section based on a DO reading at one location is almost impossible.
2. Aeration rates cannot be set for each pass but must be the same for passes 1 and 2, and passes 3 and 4.
3. Sufficient air cannot be supplied to maintain dissolved oxygen residuals during peak flow periods.

Oxygen requirements are a concern to plant supervisory personnel and procedures for eliminating two of the above mentioned problems are being examined.

The permissible flow into the final settling tanks is based on the settleability of the sludge. If good settling exists then more load may be added to the section but if sludge settleability is poor, flow to the section may be decreased. No measurement of sludge blanket depth is taken and sludge waste rates are based on 24 hour composite samples of return sludge.

Waste rates are normally between .1-.15 MIGD with return sludge rates at about 3.0 MIGD. The return sludge solids concentrations are adjusted by varying the amount of solids wasted from the system each day.

To summarize, control over the secondary is exercised in the following ways;

1. Flow into the secondary and individual sections is controlled using bypass weirs and inlet gates.
2. Sludge waste rates are based on return solids concentrations which are calculated using 24 hour composite samples.
3. Aeration rates are determined based on the dissolved oxygen values obtained in the 4th pass.

The use of these controls determines the degree of treatment that can be obtained.

Average monthly operating and performance data (1974) for the City of Edmonton Activated Sludge process is shown in TABLE 1. Based on the values in TABLE 1 some loading parameters and detention times are calculated and compared, in TABLE II, with values reported by other

TABLE I AVERAGE MONTHLY OPERATING AND PERFORMANCE DATA FOR CITY OF EDMONTON ACTIVATED SLUDGE PROCESS (1974)

Month	Flow thru each section (MIGD)	Air flow to each section (MCFD)	RSSS (mg/l)	MLSS (mg/l)	Return solids flow (MIGD)	BOD		SS	
						lbs added to each section (lbs/day)	% removal	lbs added to each section (lbs/day)	% removal
Jan	8.1	11	6,200	2,000	3.0-3.2	18,000+	78	13,500	74
Feb	8.2	10	6,900	2,000	3.0-3.2	13,500	87	11,000	85
Mar	8.0	9	6,800	2,000	3.0-3.2	13,500	83	14,000	81
Apr	13.0	4	16,000	3,300	3.0-3.2	12,500	82	39,000 *	90
May	12.3	6	11,000	2,300	3.0-3.2	12,000	77	12,000	74
June	12.1	7	10,300	2,100	3.0-3.2	10,500	80	9,000	73
July	12.7	9	9,500	2,100	3.0-3.2	9,000	78	12,000	84
Aug	10.8	13	7,500	1,700	3.0-3.2	11,000	78	9,000	79
Sept	10.8	13	8,000	1,800	3.0-3.2	12,000	80	9,000	82
Oct	9.5	12	6,800	1,800	3.0-3.2	17,000	82	12,000	77
Nov	7.7	12	5,400	1,500	3.0-3.2	13,500	79	9,500	73
Dec	7.4	11	4,900	1,400	3.0-3.2	10,000	78	8,000	63

+ high BOD packing plant wastes treated at the plant

* spring runoff (large amounts of inorganic solids)

TABLE II OPERATING DATA FOR ACTIVATED SLUDGE PROCESS

ITEM	GOODMAN (1971) TWO STAGE AERATION	HASELTINE (1961) EXTENDED AERATION	WPCF MANUAL #8 (1967) (GENERAL PRACTICES)	EDMONTON NORMAL OPERATION
Aeration Tank				
MLSS (mg/l)	3,000	1,700-5,100	1,500-4,000	2,000
RSSS (mg/l)	6,000	4,700-10,000		6,500
Return Sludge (% of sewage flow)	100	41-104	25	33
Aeration time for: - mixed liquor (hr)	1.5	0.4-2.2	.5-1.5	1.2-3.6
- Return sludge (hr)	7.5	1.6-5.7	1-4	4.8
BOD loading (lbs BOD/100 lbs MLSS)			50	35
Final Settling Tank				
Surface loading ($g.d/ft^2$)		400-500	1,000	810
Detention Time (hr)		1.3-4.0		2.4

sources. The information in TABLE II indicates that operating values at the Edmonton plant are similar to those in other plants. The values given are average daily values and do not show the diurnal variations that exist. At the Edmonton plant, peak flow values may be as high as 1.5 times the average daily values. It is during peak flow periods, or times when organic loadings change dramatically, that disruption of treatment is most likely to occur.

TABLES A1 to A5, APPENDIX A, contain the average daily performance and operating data for all the secondary treatment sections during the period of this investigation.

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CHAPTER III

OPERATION OF AN ACTIVATED SLUDGE SLUDGE PROCESS USING A GROWTH RATE CONTROL

3.1 General

At the Edmonton plant the control of the solids concentration in the activated sludge systems is based on removal efficiencies. Solids concentrations are maintained at a relatively fixed level until treatment efficiencies show that a change must be made. The problems associated with this type of control procedure are:

1. It assumes relatively steady state loadings and,
2. It allows changes to be made only after treatment efficiencies have dropped.

To eliminate these problems, a means of control that considers loading variations immediately is necessary.

In the following chapter a control procedure which considers loading variations is developed, discussed and applied to the operation of a secondary treatment section at the Edmonton plant. The results and conclusions of the study are also presented. Before the control procedure is developed, however, a review of some activated sludge control practices is presented to illustrate the need for and development of this control procedure.

3.2 Review of Activated Sludge Control Practices

The effective operation of an activated sludge system depends on the design factors built into it, the operation of the system with respect to these factors, and the controls available to maintain desired performance *(Kraus, 1965)*. In most activated sludge plants the operations that can be controlled are rate of recirculation, sludge waste rate and aeration rate *(Lacroix, 1972)*.

The two characteristics of activated sludge that are most commonly used in control are the mixed liquor suspended solids concentration (MLSS), and the sludge volume index (SVI). MLSS is the concentration of solids in the aeration mixture of sludge and the SVI is defined as the volume in millilitres, occupied by one gram activated sludge after settling the aerated liquor for 30 minutes *(Standard Methods, 1971)*. The sludge volume is determined as follows:

$$\text{SVI} = \frac{\text{\% settling by volume}}{\text{\% suspended matter by weight}}$$

The sludge volume index is indicative of sludge settling characteristics. SVI of less than 100 are associated with good settling sludges and values of 200 are indicative of poor settling characteristics.

Good control of the activated sludge process has been obtained by maintaining a fixed MLSS concentration in the aeration tank *(McKinney and O'Brian, 1968)*. In this method the amount of activated sludge carried within the system depends on the strength and character of the wastes being treated, the design of the facility, treatment requirements and other factors. The criteria used to determine how much activated sludge should be carried in the system is usually based on effluent characteristics. Normal concentrations of MLSS range between 1,500 to 3,000 mg/l *(Lacroix, 1972)*.

Control of MLSS concentrations is carried out by wasting sludge at a controlled rate. Because the concentration of the sludge is dependant on the SVI it is possible to establish a relationship between MLSS and SVI. *Bloodgood (1948)* reported that the sludge balance for an activated sludge plant on any given day should show that the amount of mixed liquor solids equals the amount of return sludge solids assuming no gain or loss of solids occurs. The relationship between mixed liquor and return solids is given by:

$$(1 + a)fx = afcx \qquad (1)$$

where

f = sewage flow, mgd
af = return sludge flow, mgd
a = volumetric return sludge ratio
x = mixed liquor concentration, mg/l
cx = return sludge solids concentration, mg/l
c = return sludge concentration factor

$$cx = \frac{10^6}{SVI} \qquad (2)$$

Substituting Equation (2) into Equation (1) gives:

$$(1 + a)fx = af\,\frac{10^6}{SVI}$$

or

$$a = \frac{1}{\left(\frac{10^6}{(SVI)(x)}\right) - 1} \qquad (3)$$

To maintain a fixed MLSS concentration or constant value of x in equation (3) requires only that the SVI be known. Once the value of SVI is determined the correct return sludge ratio can be calculated.

The use of food to micro-organism ratio as a control parameter in the operation of the activated sludge process is also common practice. The food to solids ratio (F:S ratio) is expressed as pounds of BOD applied per day per pound of mixed liquor suspended solids in the aeration tank. The control of F:S ratio is usually carried out by varying the MLSS concentration. The MLSS concentration is changed by varying the value of a according to equation(3). The relationship between MLSS concentration and F:S ratio is given by:

$$x = \frac{f\,S_1}{V\,L} \qquad (4)$$

where x = mixed liquor concentration, mg/l
f = sewage flow, mgd
S_1 = BOD concentration applied to aeration tank, mg/l
V = volume of aeration tank, ml
L = BOD loading, lb of BOD/lb of MLSS/day

Substituting equation (4) in Equation (3) gives:

$$a = \frac{1}{\frac{10^6 (V)(L)}{(SVI)(f)(S_1)} - 1} \qquad (5)$$

The value of a depends on SVI, BOD load chosen and the BOD concentration of the wastewater. Equation (5) is much more applicable to the operation of most activated sludge plants than equation (3) because variations in BOD loadings are considered *(Haseltine, 1956; Vosloo, 1970)*.

One of the main difficulties encountered when applying equations (3) and (5) in the control of activated sludge processes is that good sludge settleability is often difficult to maintain *(Pipes, 1966)*. A definite factor in the inability of equations (3) and (5) to give sludges of good settleability is that they are parameters that can be used on a daily basis only, due to the analysis required in the determination of the value of a. Another serious limitation of equation (5) is that the value of S_1 is changing continually and to make the necessary changes in a to accommodate these variations would be extremely difficult. The relationships are based on general mass balances and do not directly consider the growth kinetics of the organisms involved.

A procedure using microbial growth as a control parameter was proposed by *Garrett and Sawyer (1952)*. This procedure has been developed to give a control parameter that allows immediate control of F:S ratio and is therefore a better operational tool *(Walker, 1971)*.

3.3. Kinetics of Biological Growth

By examining the kinetics of biological growth in activated sludge processes it is possible to develop controls, that are not based on physically determined mass balances but rather on the predicted behaviour of the system to waste loadings.

The relationship most commonly used to relate substrate removal and microbial growth in biological systems is *(Stanier, 1970)*:

$$\frac{dX}{dt} = Y\ dF/dt - KdX \qquad (6)$$

where $\frac{dF}{dt}$ = substrate removed per day (lbs. of BOD/day)

$\frac{dX}{dt}$ = new cell produced per day (lbs)

Y = growth rate coefficient
Kd = endogenous respiration rate
X = mass of organisms in the system.

Many investigators have used this equation to develop control parameters for the activated sludge process *(Garret, 1958; Jenkins and Garrison, 1968; Uhte, 1970; Walker, 1971; Burchett and Tchobanoglous, 1974)*.

The rate of substrate removal is given by the following *(Metcalf and Eddy, 1972)*:

$$\frac{dF}{dt} = \frac{KXS}{K_s + S} = \frac{dS}{dt} \qquad (7)$$

where K = maximum rate of waste utilization per unit weight of micro-organism, time $^{-1}$
K_s = waste concentration at which the rate of waste utilization per unit weight of micro-organism is one-half the maximum, rate mass/volume
S = concentration of waste available to the micro-organism, mass/volume

If the value of S is large in relation to K_s then substrate utilization proceeds at a maximum rate K, but if S is small (limiting) then removal rate decreases. Equation (7) is similar to the one developed by *Monod (1949)*.

If equation (6) is divided by X the following relationship results:

$$\frac{dX/dt}{X} = Y \frac{dF/dt}{X} - Kd \qquad (8)$$

The term $\frac{dX/dt}{X}$, net growth rate, is often written as $1/\theta_c$ and can be expressed as:

$$1/\theta_c = Y \frac{UmS}{K_s + S} - Kd \qquad (9)$$

where $1/\theta_c$ = growth rate, time $^{-1}$
Um = maximum growth rate, time $^{-1}$

Also a relationship using equations (8) and (9) can be developed which shows the effect of solids concentrations on substrate removal, dilution rate (detention time) and microbial growth rate *(Lacroix, 1972)*. FIGURE 6 shows a

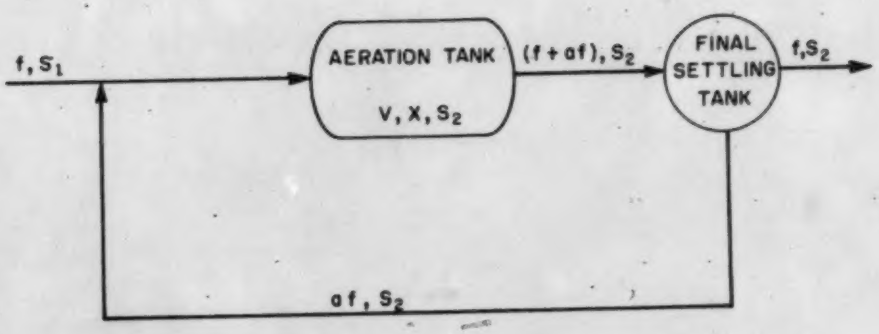
f, S_1
AERATION TANK
V, X, S_2
(f + af), S_2
FINAL SETTLING TANK
f, S_2
af, S_2

FIGURE 6: FLOW DIAGRAM OF A CONVENTIONAL ACTIVATED SLUDGE SYSTEM

flow diagram of a conventional activated sludge system.

The nomenclature for FIGURE 6 is as follows:

f = sewage flow rate
S_1= concentration of substrate in the influent
V= volume of aeration tank
X = concentration of cells in the aeration tank
S_2= concentrationof substrate in effluent
af= return cell flow
a = ratio of the return to the medium flow

A mass balance can be written for substrate removal in the aeration tank as follows:

rate of change of substrate = rate of input - rate of output + rate of consumption in aerator

$$\frac{VdF}{dt} = fS_1 + afS_2 - (1+a)fS_2 - V\left(\frac{dX/dt}{Y} + \frac{KdX}{Y}\right) \quad (10)$$

The rate of consumption $\left(\frac{dX/dt}{Y} + \frac{KdX}{Y}\right)$ is obtained from equation (6). For steady state conditions equation (10) becomes:

$$V(0) = f(S_1-S_2) - V\left(\frac{dX/dt}{Y} + \frac{KdX}{Y}\right) \qquad (11)$$

rearranging gives

$$dX/dt + KdX = \frac{f}{V}\ Y(S_1-S_2) \qquad (12(a))$$

or

$$X = \frac{\frac{f}{V}\ Y(S_1-S_2)}{\frac{dX/dt}{X} + Kd} \qquad (12(b))$$

$$\frac{f}{V} = \text{Dilution rate } D$$

The relationship is now

$$X = \frac{DY(S_1-S_2)}{\frac{dX/dt}{X} + Kd} \qquad (13(a))$$

or substituting $1/\theta_c$ for $\frac{dX/dt}{X}$ gives

$$X = \frac{DY(S_1-S_2)}{1/\theta_c+Kd} \qquad (13(b))$$

Equation (13(b)) shows that there are many values of X and D that will give the desired value of $1/\theta_c$. This means then, that if detention times are increased, in aeration tank, due to decreasing flows, the value of X must be decreased. The most widely used equation in activated sludge process control is equation (8). The term $\frac{dX/dt}{X}$ is symbolized by $1/\theta_c$ and $\frac{dF/dt}{X}$ is symbolized by U. Equation (8) now becomes:

$$1/\theta_c = YU-Kd \qquad (14)$$

Before the application of equation (14) to the operation of the activated sludge process is discussed, some of the limitations and assumptions of the relationship should be noted *(Eckenfelder, 1966; Metcalf and Eddy, 1972; Sherrard and Schroder, 1973)*:

1. Storage of substrate by the micro-organisms does not occur.
2. Athough the growth constant Y is considered constant some of the factors influencing this coefficient are:
    (a) oxidation reduction state of carbon source - the more energy available from the substrate the higher will be the yield.

(b) oxidation reduction state of nutrient elements.

(c) presence of growth factors such as amino acids and vitamins-cellular energy does not have to be expended on synthesizing these compounds since they are already available.

(d) degree of polymerization of the substrate-longer chained carbon molecules can be used to synthesize the longer chained carbon molecules found in the cell easier than the shorter chained molecules can.

(e) pathways of metabolism - metabolic pathway utilized by the micro-organisms (higher yield of adenosinetriphosphate (ATP) is associated with higher yield coefficients.

(f) growth rate of the micro-organism- cells growing rapidly expend more energy for growth and divert little energy for maintenance whereas cells growing slowly expend greater portions of energy for maintenance.

(g) various physical parameter such as-PH, salinity temperature and dissolved oxygen.

(h) predator activity.

3. All essential nutrients are present and the only substance limiting growth is the organic matter in the waste stream.

4. Because the relationship has been developed using bacterial growth characteristics it applies only to systems where bacteria are the predominant organism.

5. The equation applies only to soluble substrates

6. The equation is empiric and has been developed for activated sludge processes.

To some extent all of the assumptions regarding the application of equation (14) are violated. *Metcalf and Eddy (1972)* state that micro-organisms predominate in activated sludge and that for most activated sludge processes, treating domestic waste, the empiric relationship is valid. Temperature, pH and dissolved oxygen are three physical parameters which affect the value of the growth constant Y, and limit growth.

Maintaining optimum levels of pH and temperature is impossible at most treatment facilities. If the nature of the waste being treated does not change significantly with time, then the micro-organisms within the system become acclimatized and steady state values of Y and Kd exist, provided that all other factors are optimum. Changes in pH are temperature will result in changes in Y and Kd and therefore seasonal variations in control limits may be necessary.

Supplying sufficient dissolved oxygen to the micro-organisms is also a problem in many activated sludge processes. If sufficient oxygen is present to maintain aerobic conditions within the matrix of the biological floc the rate of bacterial respiration will not be limited by dissolved oxygen ocncentrations *(Kalinske, 1971)*. That is to say, respiration rate will not change if dissolved oxygen is increased, but the rate will decrease if DO drops below a certain minimum level. *Mueller et al (1967)* have shown that the diffusion of oxygen through the biological floc is what controls the rate of oxygen utilization. For a floc of diameter 100u the limiting concentration may be as high as 4 mg/l, whereas the critical oxygen concentration for dispersed cells is only .1 mg/l. *Englande and Eckenfelder (1972)* have reported that a dissolved oxygen residual of 1 mg/l will ensure aerobic conditions within flocs of the typical size encountered in the activated sludge process.

Dissolved oxygen concentration is the only factor affecting the values of Y and Kd which can be controlled in the Edmonton activated sludge process. All the other factors are a function of the waste being treated.

3.4 Application of Microbial Growth in Control of the Activated Sludge Process

The application of $1/\theta_c = YU - Kd$ in control of activated sludge processes has been studied extensively *(Garrett 1958; Jenkins and Garrison, 1968; Walker 1971; Zagic, 1971; Burchett and Tchobanoglous, 1974)*. In the equation:

$$\theta_c = \frac{\text{mass of organisms in the system}}{\text{mass of organisms grown(wasted)per day}}$$

$$= \text{mean cell residence time, MCRT, days.}$$

$$U = \frac{\text{food removed per day}}{\text{mass of organisms in the system}}$$

$$= \text{food to micro-organism ratio (F:M)}$$

$$= \frac{\text{lbs of BOD removed per day}}{\text{mixed liquor volatile suspended solids (MLVSS)}}$$

Y = growth constant relating amount of activated sludge produced per lb of BOD removed.

Kd = endogenous respiration rate, gives the portion of activated sludge oxidized to provide energy for the cell to carry on normal cellular activity.

The values of Y and Kd are unique for a particular waste and waste treatment system but values for Y between 0.5 and 0.6 are common for most domestic wastewaters and values of Kd are usually between 0.04 and 0.05 *(Walker, 1971; Gaudy and Gaudy, 1971)*. *Peaner and Martinson (1974)* report that two schools of thought exist regarding the application of equation (14) and the values of Y and Kd. Some investigators include the settling tank solids when considering cell growth. Whether or not significant microbial activity takes place in the settling tanks is probably a function of the particular operation and waste.

It has been found that optimum removal of organics occurs when the food to micro-organism ratio is maintained within a fixed range. Because abrupt changes in the activated sludge organism's environment reduces their efficiency, it is desirable to keep the F:M ratio as constant as possible *(Jenkins and Garrison, 1968; Walker,1971; Burchett and Tchobanoglous, 1974)*. Two methods can be used to control the F:M ratio. One method involves directly measuring F:M ratio and the other controls F:M ratio by varying the MCRT (mean cell residence time). This is possible if the values of Y and Kd are relatively constant for a particular system.

Controlling the F:M ratio directly, by measuring the influent food load and adjusting the solids level accordingly, should give a sludge of good settleability and effluents of high quality. There are, however, two serious limitations encountered when applying this method to actual operation. The first drawback is encountered in determining the food loading. BOD determinations give after the fact information and the use of COD or TOC values are necessary. This involves a considerable amount of laboratory analysis especially if continuous control is necessary. Another disadvantage of controlling F:M ratios directly is that the MLVSS concentration is not an accurate measurement of the organisms within the system. If all the organisms died in the system the MLVSS concentration would still remain the same. Therefore by maintaining a constant BOD, TOC and COD-VSS concentration we are not necessarily maintaining a constant F:M ratio.

The other method of controlling F:M ratio involves using MCRT. Mean cell residence time is the same as sludge age, a common term used in activated sludge plant operation. Control of F:M ratio by MCRT applies equation (14) and involves the following five steps *(Walker, 1971);*

1. Select the desired F:M ratio and using known values of Y and Kd determine the value of θ_c.
2. Determine total mass of solids in the system.
3. The mass of solids to be wasted is determined by dividing the total mass of solids in the system by θ_c.
4. The concentration of solids in the waste stream is calculated.
5. The waste rate is adjusted so that the total mass of solids to be wasted per day, step 3, are wasted based on concentration in waste stream, step 4.

By controlling to a fixed MCRT a constant F:M ratio is maintained. In addition, there are several advantages to the MCRT control procedure. First, by controling to MCRT the amount of laboratory analysis is reduced and only solids measurements are necessary. The second advantage is that wasting a certain amount of the total solids (TS) eliminates the problem of what per cent of the solids are viable organisms. If 20% of the TS are wasted then 20% of the active organisms are wasted *(Walker, 1971)*.

The disadvantages of this method are:

1. Changes in daily load are not considered directly.
2. An inventory of the solids in the system must be made each day, and

3. The concentration of solids in the waste line and the waste rate must be determined each day. These disadvantages can be eliminated by using an alternate method of controlling MCRT called hydraulic control.

Controlling MCRT by a completely hydraulic control requires that a certain per cent of the solids be wasted each day. This method takes into account changes in secondary flow by varying the waste rate (e.g. if secondary flow increases the number of passes a unit of sludge will make through the system increases and the sludge waste rate must be decreased). In an activated sludge process the waste rate is determined by the following procedure:

1. Return sludge rate is set.
2. Sewage flow is estimated
3. Detention time throughout the process is calculated.
4. The number of passes the sludge makes through the system is determined.
5. The desired MCRT is chosen.
6. The waste rate as a per cent of the return rate is calculated based on the value of MCRT used.

Using this procedure charts can be made that give the desired waste rate for any given flow and fixed values of MCRT and return sludge rates. Once the flow is measured a change in waste rate can be made immediately simply by reading the value off the appropriate chart. The advantagesof this type of control are:

1. Food to micro-organism ratio is controlled with no laboratory analysis required.
2. Controlling waste rate based on MCRT gives immediate control for changes in hydraulic and organic load *(McKinney, 1962)*.
3. Problems regarding the application of the equation $1/\theta_c=YU-Kd$ to particular activated sludge processes and the exact values of Y and Kd are of academic interest only because an operating range for MCRT can be established that gives desired treatment.. Once this range is established the F:M ratio is optimized for the particular system.

The major assumption made in application of the above procedure is that the solids in the effluent are negligible. During periods of sludge bulking, modifications to the system must be made and once normal settling is obtained the procedure may be again implemented. The procedure also assumes that relatively steady state conditions exist (i.e. no sudden changes in pH, temperature, organic loading etc. occur).

The use of microbial growth kinetics in activated sludge process control has been successful in many small treatment facilities and modifications of reactor designs to facilitate these controls have been studied *(Burchett and Tchobanoglous, 1974)*.

3.5 Description of Study

3.5.1 The Study

Between June 17 and August 2, 1974 an hydraulic control procedure which maintained a constant F:M ratio was employed in section 4. The main objective of the study was to develop an operational control which would result in higher removal efficiencies and was amenable to existing process controls.

3.5.2 Hydraulic Control of F:M Ratio at the Edmonton Plant

Normal operation of secondary treatment sections at the Edmonton plant during the study period involved addition of influent along the complete length of both the 2nd and 3rd passes of each section. The solids concentration was controlled by keeping a constant return sludge suspended solids concentration. Because this control procedure did not consider changes in influent loading a control method which did, hydraulic control of F:M ratio, was tried in a section and removal efficiencies for each compared. Solids concentrations and dissolved oxygen were also obtained and compared to those for sections operating normally.

The procedure for controlling the F:M ratio hydraulically was reviewed in section 3.4. The application of this procedure to the Edmonton activated sludge process is described in APPENDIX B. FIGURES B1-B5 give waste rates for almost all operating conditions where primary effluent is added along the beginning of the second pass. Once FIGURES B1-B5 were obtained the control of a section using this procedure was relatively simple. A return rate was fixed, a value of MCRT chosen and then the waste rate was known for all influent flows. To use this control then, influent flows had to be continually available and waste rates had to be such that they were easily and accurately controllable. Unfortunately, neither of these conditions existed at the Edmonton plant.

Accurate flow values for total secondary influent were available but the flow to each individual section is calculated using a questionable procedure (section 2.3.2). Controls on the waste pumps were such that the slightest adjustment resulted in changes of .05 MIGD in the waste rate. This made it exceedingly difficult to vary the waste rates less than .05 MIGD at a time. The main waste line which carries the waste from all five sections also carried scum collected from the top of the final settling tanks. The scum was collected in a storage tank which had to be pumped out approximately every five minutes. When the scum was pumped the waste rates would drop significantly due to increased pressure in the main line. This resulted in continuous fluctuations in waste rates.

The problem of fluctuating waste rates was overcome by transferring the waste from the test section directly into another section thus bypassing the main waste line. The problem regarding influent flow rates and waste rate controls were more difficult to solve and it was finally decided that a constant waste rate would have to be used. At first glance it would appear that this defeated the purpose of the hydraulic control procedure. If an examination of FIGURES B1-B5 is made however, it becomes apparent that for the normal influent flows (6-12 MIGD per section) received at the Edmonton plant, the value of the required waste rate changes very little A fixed value for the waste rate seemed justified.

Once these problems had been solved it was necessary to decide on the value of the return rate and the desired MCRT. For this study a return rate of 3 MIGD was chosen because it was the maximum pumping rate that gave the least operational problems. Higher pump rates often resulted in overheating especially during the summer months. Return rates of less than 3 MIGD were not chosen because this would have resulted in longer reactivation times. Once the return rate was set the MCRT values had to be fixed. In activated sludge processes that receive large daily variations in loading a slightly lower food to microorganism ratio is recommended because it allows for increases in loading. A F:M ratio of .3 was chosen using this criteria. All the necessary information for hydraulic control using a return rate of 3 MIGD and a F:M ratio of .3 is given in FIGURE B3. The F:M ratio of .3 gives a MCRT value of 10-12 days assuming Y=.5-.6 and Kd=.04-.05.

All the necessary information was now available and the control procedure could be applied to a section at the Edmonton plant.

Part 1 of this study involved operating section 4 using hydraulic control of F:M ratio. A return rate of 3 MIGD and a MCRT value of 10-12 days were chosen. Waste rate was fixed according to FIGURE B3 at .1-.12 MIGD. Waste sludge was pumped into section 3. Section 4 was operated in this way from June 17 to August 2. During this test period sections 1 and 5 were also in continuous operation using normal control procedures. Also during this period section 3 was operated using recycle. In the recycle system 3 MIGD of mixed liquor was pumped from the end of the 4th pass to the beginning of the 1st pass. A fixed solids concentration was maintained in the system.

Operating data obtained for section 4 was compared to that obtained from section 1, 3 and 5. Dissolved oxygen profiles were obtained for section 4 and compared to those from other sections. Average daily operating data for sections 1, 3, 4 and 5 during this test period is given in APPENDIX A, TABLES A1, A2, A3 and A4.

Based on the data collected from the above portion of the study it was decided to use the hydraulic control procedure on a section using recycle. The recycle pump was moved to Section 1 and was started August 20. The use of hydraulic control on this section was attempted through the remainder of August and all of September. Continual disruption of treatment occurred and it was finally decided to shut the recycle pump off and abandon this portion of the study.

Much of the information used in this part of the study was obtained from the sewage treatment laboratory. BOD and suspended solids values for secondary influent, return sludge, mixed liquor and final effluent were supplied by treatment plant personnel. Dissolved oxygen profiles using an Ionics Dissolved Oxygen Analyser and a Yellow Springs Dissolved Oxygen Analyser were obtained by the author with the aid of a technician.

Before the results of this study are presented and conclusions draw, a point that was briefly touched upon in Section 3.4 regarding the advantages of the hydraulic method, should be studied at this point in more detail. In Section 3.4 it was mentioned that the exact values of Y and Kd did not have to be known to use the hydraulic control procedure. The usefulness of the procedure is that various values of MCRT can be tried for a particular process and those values which yield the best treatment efficiencies used. Even though the absolute value of MCRT used is wrong, because the values of Y and Kd used are not correct, the procedure is still valuable as a control device.

3.6 Data Collected

To evaluate the effectiveness of the hydraulic control procedure, treatment efficiencies from Section 4 which was controlled hydraulically between June 17 and August 2, were compared to the other sections operating during the same period. BOD and suspended solids concentrations in each sections effluent are plotted and presented in APPENDIX C, FIGURES C1-C6. The values from these FIGURES are presented in tabular form in TABLE III. TABLE III gives means, standard deviations and ranges of each section's effluent BOD and suspended solids concentration during the period of the test. FIGURE 7 presents typical dissolved oxygen curves based on average values obtained from 63 dissolved oxygen profiles taken from the four sections, operating during the study period.

In FIGURES C1, C2 and C3, BOD values in the final effluent from sections 1, 3 and 5, respectively, are compared to those in section 4, the hydraulically controlled section. All three figures show that, on most days the sections all exhibited the same trend (i.e. when the BOD of the effluent fell in one section it usually fell in the others). The level to which the BOD value rose or fell, however, varied for each section. FIGURE C2 shows that sections 3 and 4 give almost the same quality of effluent throughout the study period. TABLE III shows that the two sections were very close in degree of BOD removal but it is significant to note the difference between the flows treated by each section. FIGURE C3 which compares the BOD of the effluents from sections 4 and 5, shows that on several occasions the BOD in section 5's effluent was significantly higher than that in section 4. This is also shown in TABLE III. Both Section 1 and 5 were controlled by the procedure normally used at the Edmonton plant. The only difference between the operation of the two sections during the study was that section 5 received more flow than Section 1. FIGURE C1 compares section 3's effluent BOD concentrations to Section 4's. During the comparison period Section 3 was operated with a recycle. The comparison period is very short and control of the recycle section during this time was entirely experimental, so it is difficult to make an evaluation of the recycle system, but FIGURE C1 shows that the section gave effluents slightly higher in BOD than section 4. This is also reflected in TABLE III. To summarize the BOD comparisons; sections 1, 3, 4 and 5 gave approximately the same BOD removal but section 1 received less flow. Section 5 which was operated the same as section 1 gave slightly poorer treatment.

In FIGURES C4, C5 and C6 suspended solids concentrations in the final effluent from sections 1, 3 and 5 respectively are compared to those in section 4. As in the BOD comparisons, the comparison of suspended solids concentrations shows that the effluents from section 1, 3 and 4 are very similar in quality with section 4 again giving the best removal. The difference between section 5 and the other sections is very dramatic. Section 5 showed extremely poor settling characteristics on numerous days during the test and this is reflected in the very high mean suspended solids concentration of the section's effluent.

The information presented in FIGURES C1-C6 is summarized in TABLE III. TABLE III shows that, except for the suspended solids removal by section 3, section 4 gave the best BOD and suspended solids removal of the four

TABLE III FINAL EFFLUENT COMPARISON BETWEEN SECTION 4 AND SECTIONS 1, 3 AND 5,[a] EDMONTON SEWAGE TREATMENT PLANT

ITEM	Sections 1	4	Sections 3	4	Sections 5	4
Period of Operation	June 25-Aug 2		July 2-17		June 17-Aug 2	
BOD (mg/l)						
Mean	17.5	16.4	18.9	15.4	19.9	17.7
Standard Deviation	10.5	6.6	8.6	7.3	10.1	6.8
Range	68-3	38-6	39-7	38-6	46-4	38-6
SUSPENDED SOLIDS (mg/l)						
Mean	17.3	16.7	15.6	16.4	28.8	17.5
Standard Deviation	9.0	7.9	5.8	7.1	23.3	9.0
Range	54-1	36-3	24-4	28-3	133-6	46-3
FLOWS (MIGD)						
Mean daily	12.1	13.7	14.4	14.4	12.6	13.4

[a] Supplementary data contained in TABLES A1-A4

sections in operation. Section 4 also treated more waste during this period than sections 1 and 5 and the same amount of waste as section 3.

FIGURE 7 shows dissolved oxygen profiles of the four sections. Very little difference can be seen in the profiles along the second and third passes but the first pass values for section 1 reflect the recycle of fourth pass mixed liquor which contains a high dissolved oxygen. Values along the fourth pass shows the same trend for all Sections. It is interesting to note that although the return sludge suspended solids concentration in section 4 was much less than that of section 1 and 5, the DO profiles of the three sections were almost identical.

3.7 Summary and Recommendations

This study which used an hydraulic control procedure to maintain a fixed F:M ratio in a treatment section at the Edmonton plant, yielded surprising and satisfying results. The surprising part of the study was the ease at which the control procedure was applied and the fact that it required very little operator time. The satisfying result of the study was that the control procedure gave excellent treatment efficiencies, better efficiencies than the other three sections in operation during the same period.

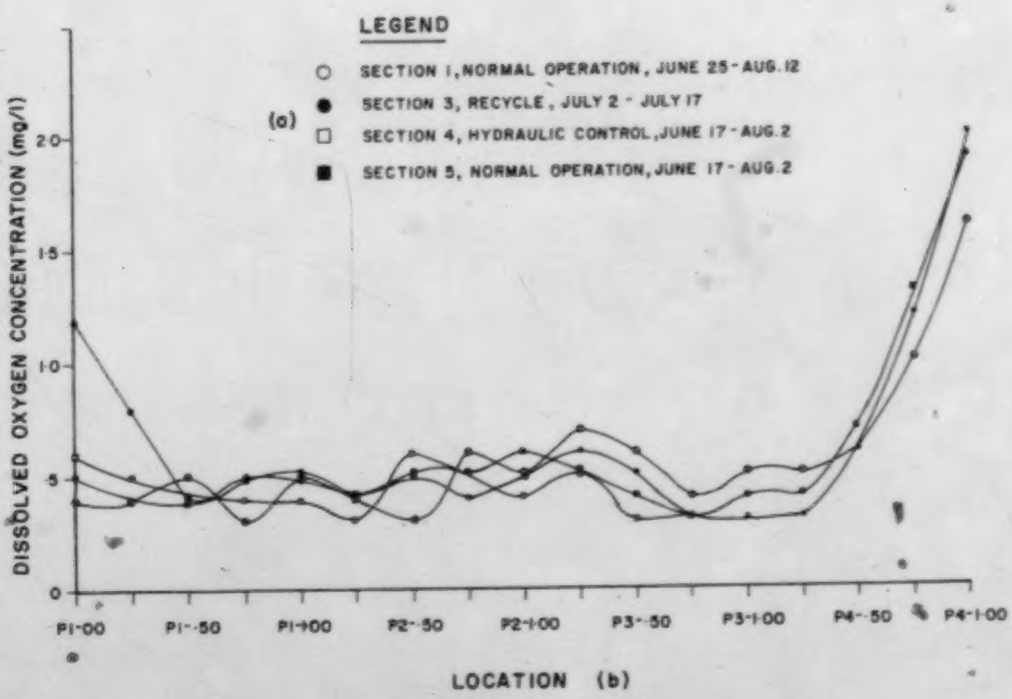

FIGURE 7: AVERAGE DISOLVED OXYGEN DATA FOR SECTIONS 1, 3, 4 & 5, EDMONTON SEWAGE TREATMENT PLANT (c)

a.) Aeration rates in last pass varied June 17 - July 21
b.) Example - P2 - ·50 = half way along pass 2
c.) Supplementary data contained in TABLE D5

The fact that section 4 gave only slightly better BOD and suspended solids removal than section 1 can be attributed to the higher flows received by section 4. It is possible to say this, because section 5, which was operated similar to section 1 except that it received more flow, gave much poorer treatment than section 1. This may indicate that the amount of solids within the system (i.e. the MLSS concentration) may not be critical at lower flow rates but at higher flow rates, when surface loading values are high, the concentrations may be much more critical. The recycle system is difficult to discuss since it was being tried for the first time during this study period. Based on the treatment comparisons it would appear that the use of recycle may be a useful tool in process operation.

Further investigation into the use of hydraulic controls, for controlling F:M ratio, appears to be warranted. If waste rates could be controlled to .01 MIGD it would be possible to vary the waste rates according to influent flows and thus make fuller use of this control procedure. During the writing of this study, plans for examining the waste controls at the Edmonton plant were underway. Further investigations should also examine and compare treatment efficiencies obtained for a broad range of F:M ratios. FIGURES B1-B6 can be used to set the waste rates for various

F:M ratios provided addition of waste is started at the beginning of pass 2. If sufficient F:M ratios are experimented with then the optimum operating conditions for the process will be obtained.

The dissolved oxygen profiles illustrate the point that aeration requirements of the sludge are not being met. The recommended value for DO concentration of 1 mg/l is not obtained until half way along the final pass in any of the sections. The lack of sufficient oxygen along the first pass may be particularly deleterous to sections that are controlled using a high concentration of solids. For example, section 1, 4 and 5 showed approximately the same dissolved oxygen concentrations along the first pass but section 4 had significantly less solids. If it is assumed that each unit of sludge is in the same condition as it enters the reactivation basin (i.e. each floc has the same amount of stored organics) then the higher the solids concentration the greater should be the dissolved oxygen available. If sufficient oxygen is not supplied along the first pass, reactivation of the sludge will have to occur along the second pass and treatment efficiencies may suffer. This may indeed be happening and could in part explain the poorer removal efficiencies obtained in section 1 and 5. The high dissolved oxygen concentration at the beginning of the first pass of section 1, as a result of recycling could be quite beneficial in helping to meet the high oxygen demand of the return sludge.

The dissolved oxygen data collected during this study show that aeration rates are insufficient to maintain the desired DO concentrations in the tanks.

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CHAPTER IV

SLUDGE REAERATION TIME

4.1 Introduction

At the Edmonton plant there is a fixed minimum reaeration volume of 93,000 cu.ft which gives reactivation times of 4-4.8 hours for the normal return sludge rates, of 3.5-3.0 MIGD. Reactivation times of this duration, appeared to be in excess of those times required to produce a biological floc with good adsorptive characteristics.

In this chapter, the theory of sludge reaeration is presented, methods for determining optimum sludge reaeration times are given and the procedures, results and conclusions of the study done on reactivation of return sludge solids at the Edmonton plant are described.

4.2 Theory of Sludge Reaeration

Sludge reaeration is necessary in activated sludge processes where detention periods in the aeration basin are insufficient for the organisms to utilize matter enmeshed, adsorbed and biosorbed into the biological floc *(Eckenfelder, 1966)*. The equation, $1/\theta_c = YU - Kd$ used in

Chapter III assumed no storage of organics or sufficient aeration time for complete oxidation of all available substrate. In many systems sludge reaeration is necessary to reach this state of complete substrate utilization because aeration times in the mixed liquor tank are too short. Such a system is employed at the Edmonton Sewage Treatment Plant (See FIGURE 3).

FIGURES 8 and 9 from *Eckenfelder (1966)* and *Gaudy and Gaudy (1971)* respectively, give schematic representations of substrate removal, sludge growth and oxygen utilization. An examination of the cell nitrogen content and oxygen uptake rate curves in FIGURE 8 indicate that the optimum time of sludge reaeration is time C. FIGURES 8 and 9 indicate that oxygen rates are at or near a maximum at time C and begin to fall off sharply after that point. In a system where the sludge is used as mixed liquor solids in the aeration tank it is desirable that the maximum number of organisms possible be present in the sludge and that theseorganisms have utilized most of their available food *(Ullrich and Smith, 1951)*. The plots of FIGURES 8 and 9 show that the optimum reaeration time for return sludge occurs when oxygen uptakes are at a maximum and that aeration after oxygen uptakes have dropped will result in auto-oxidation of the biological solids. This auto-oxidation of

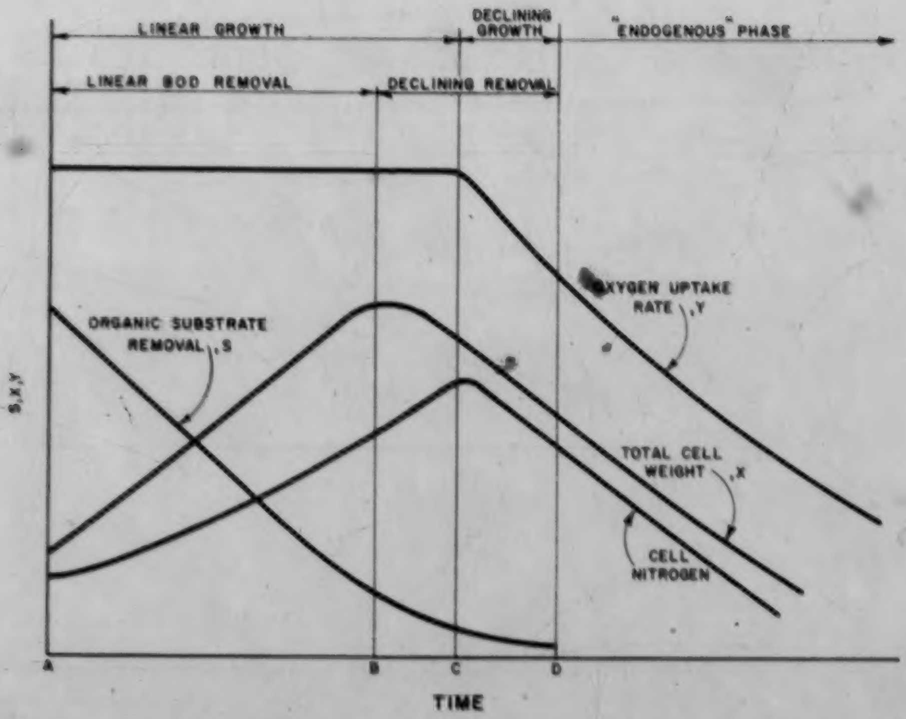

FIGURE 8: GENERALIZED PLOT FOR SUBSTRATE REMOVAL, OXYGEN UPTAKE AND BIOLOGICAL SOLIDS CONCENTRATION

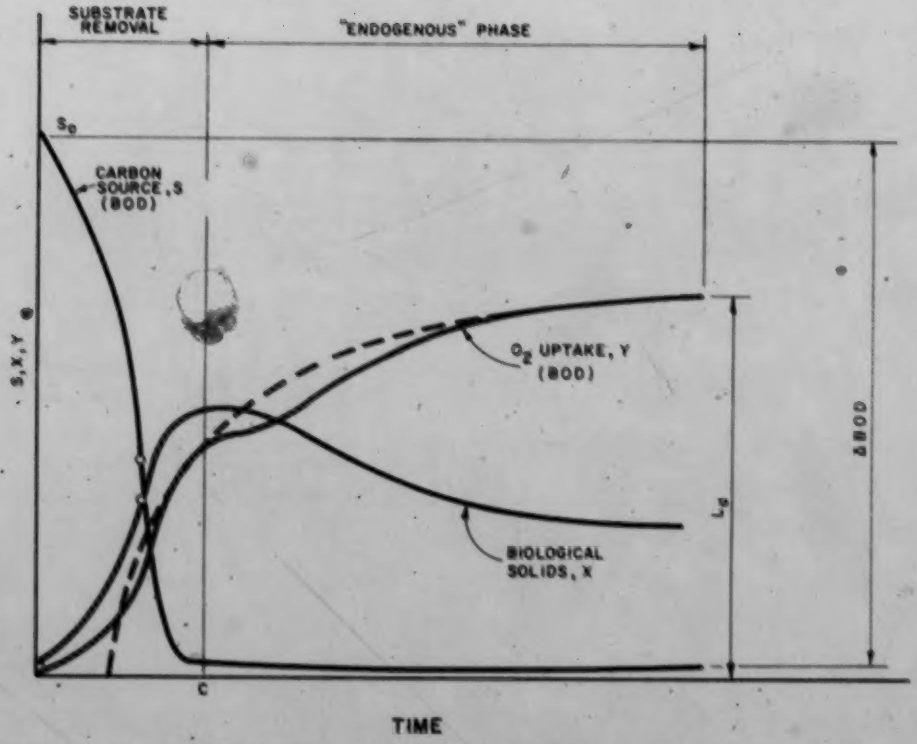

FIGURE 9: GENERALIZED PLOT OF SUBSTRATE CONCENTRATION, BIOLOGICAL SOLIDS CONCENTRATION, AND OXYGEN UTILIZATION DURING EXERTION OF BIOCHEMICAL OXYGEN DEMAND. CIRCLES MARK INFLECTION POINTS.

the sludge is part of extended aeration processes where the objective is to oxidize all the organic material.

Siddiqui et al (1967) reported that prolonged reaeration periods resulted in decreased sludge activity due possibly to inactivation of inducible enzyme systems, and increased amounts of nonbiodegradable BOD due to lysis of cells and secretion of nonmetabolizable cellular material into solution.

The desirable reaeration time is related to the aeration time. *Eckenfelder (1966) and Ullrich and Smith (1951)* give reaeration times of 90-150 minutes for aeration times of 30-60 minutes, 60 minutes for aeration times of 120 minutes and no reaeration is required if aeration time is 240 minutes. The exact reaeration time required is unique for the particular activated sludge process. The main factors affecting the required reaeration time are pH, temperature, dissolved oxygen and operation of the aeration tank (i.e. detention times and F:M ratio in the aeration tank) *(Thabaraj, 1971)*. As mentioned in Chapter III control of pH and temperature is impossible for most facilities but the dissolved oxygen can be controlled and should be above 1 mg/l. A major difficulty arises due to the relationship between F:M ratio and reaeration time *(Thabaraj, 1971)*. When the operation of the reaeration basin is modified it will result in a change in the aeration tank operation. A criteria proposed by *Siddiqui et al (1967)* uses settling characteristics as the main basis in establishing the reaeration period. The shortest possible reaeration time yielding good settling should be used.

4.3 Determination of Optimum Sludge Reaeration Time

Because sludge reaeration involves the utilization of substrate by micro-organisms any procedure that measures microbial activity can be used to determine the optimum sludge reaeration time. Five methods for measuring and studying microbial activity are given by *Pelczar and Reid (1965)*;

1. Spectrophotometer: This technique involves measuring the adsorption of light of a certain wavelength, by the particular susbtrate of interest. By measuring the absorption at intervals it is possible to determine the rate of substrate utilization.
2. Warburg Respirometer: The Warburg apparatus measures microbial activity by determining the amount of oxygen being used (FIGURE 10).
3. Thunberg Tube: This procedure is used to determine if a specific substrate can be degraded. Methylene blue (which is blue when oxidized and colourless when reduced) is used as an artificial

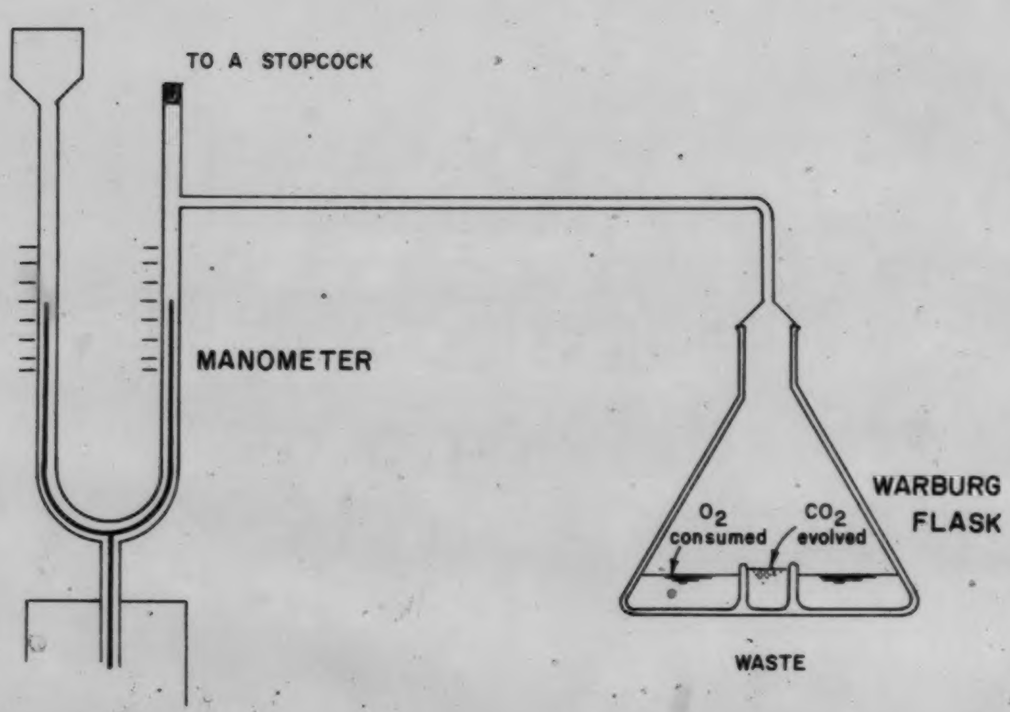
TO A STOPCOCK
MANOMETER
WARBURG FLASK
O_2 consumed
CO_2 evolved
WASTE

FIGURE 10: WARBURG RESPIROMETER

hydrogen acceptor and the indicator.

4. Radioisotope Methods: This technique involves radioactively labeling or tagging certain atoms within the substrate and examining end products for radioactive carbon atoms.

5. Chromatography: Chromatographic separation can be used to identify unknown compounds. Separation of compounds occurs in a column and identification is made by comparing the unknown compounds to known compounds in an identical column.

Of these five methods the Warburg respirometer is the most amenable to measurement of microbial activity in an aerated sewage. In mixed cultures, such as those found in the activated sludge process many different organisms are involved in the symbiotic and synergistic degradation of waste and the usefulness of spectrophotometer, radioisotope and chromatography methods are limited *(Carlson et al, 1962)*. The Thunberg tube is used to determine the degradability of specific substrates and does not measure the rate of microbial activity. The Warburg respirometer measures the amount of oxygen being utilized by the sludge. From FIGURES 8 and 9 and the following two equations:

$$\text{Organic matter} + O_2 + NH_3 \xrightarrow{\text{cells}} \text{new cells} + CO_2 + H_2O$$

$$\text{cells} + O_2 \longrightarrow CO_2 + H_2O + NH_3$$

it is apparent that when the rate of oxygen uptake begins to decrease further aeration is not required and new substrate should be added to the system (in an activated sludge process the waste to be treated should be added) *(Eckenfelder, 1966)*. The Warburg respirometer can be viewed as a continual BOD recorder. The use of BOD measurements to evaluate the biodegradability and oxygen requirements of waste is universal. The advantage of the Warburg respirometer over standard BOD determination *(Standard Methods, 1971)* is that oxygen consumption rates can be continually measured and the change in oxygen uptake recorded continuously.

One limitation exists when the measurement of microbial activity is used to determine where or when new substrate should be added in an activated sludge system. Enzymes, the organic catalysts involved in all biochemical processes essential to the life of bacteria, have a high degree of specificity for substrates and concentrations of specific enzymes vary according to the substrates being utilized *(Brock, 1970)*. The process is referred to as enzyme induction. This means that although microbial activity is high the addition of a particular substrate to the system might not result in immediate degradation of the substrate because a period of acclimiatization is necessary for the system to develop the enzymes necessary for incorporation and utilization of the substrate *(Carlson et al 1962)*. Therefore, the possible inactivation of the inducible enzyme systems through excessive sludge reaeration should be avoided.

4.4. Description of the Study

4.4.1 The Study

In an attempt to evaluate reaeration times at the Edmonton plant, oxygen uptake rates were determined on return sludge samples from two sections, each operated differently. Total solid concentrations were determined along the length of the reaeration tanks to measure any change in solids that was occurring. The purpose of this study was to evaluate the operation of the reaeration tanks at the Edmonton plant and determine whether a modification was warranted.

4.4.2 Sludge Reactivation Times

The fixed reactivation volume of 93,000 cu.ft was studied using oxygen uptake rates to determine whether detention time was excessively long. Oxygen uptake rates were determine using a Hach BOD Analyser which operates on the same principle as the Warburg Respirometer shown in FIGURE 10, Section 4.3. FIGURE 11 shows a diagram of the Hach BOD Analyser (a single cell) and FIGURE 12 is a picture of the apparatus used.

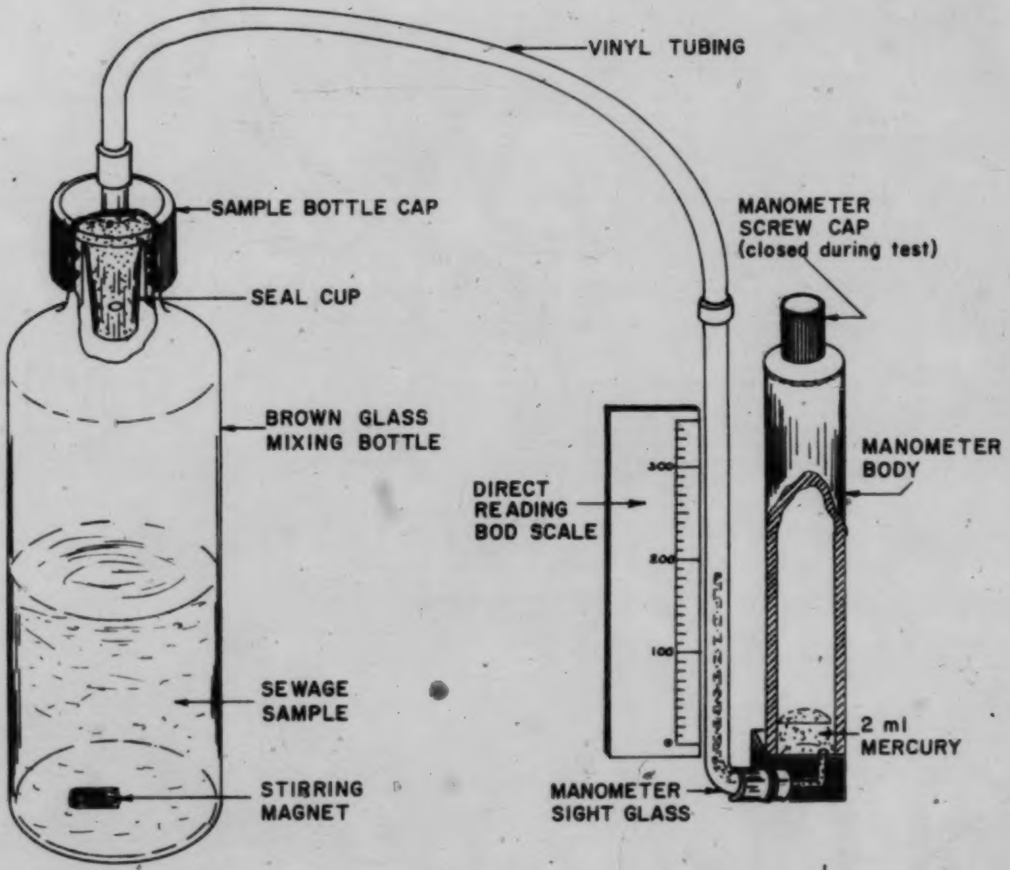
VINYL TUBING
SAMPLE BOTTLE CAP
SEAL CUP
BROWN GLASS MIXING BOTTLE
SEWAGE SAMPLE
STIRRING MAGNET
MANOMETER SCREW CAP (closed during test)
MANOMETER BODY
DIRECT READING BOD SCALE
300
200
100
0
2 ml MERCURY
MANOMETER SIGHT GLASS

FIGURE 11: HACH MANOMETRIC BOD APPARATUS (SHOWING ONE CELL ONLY).

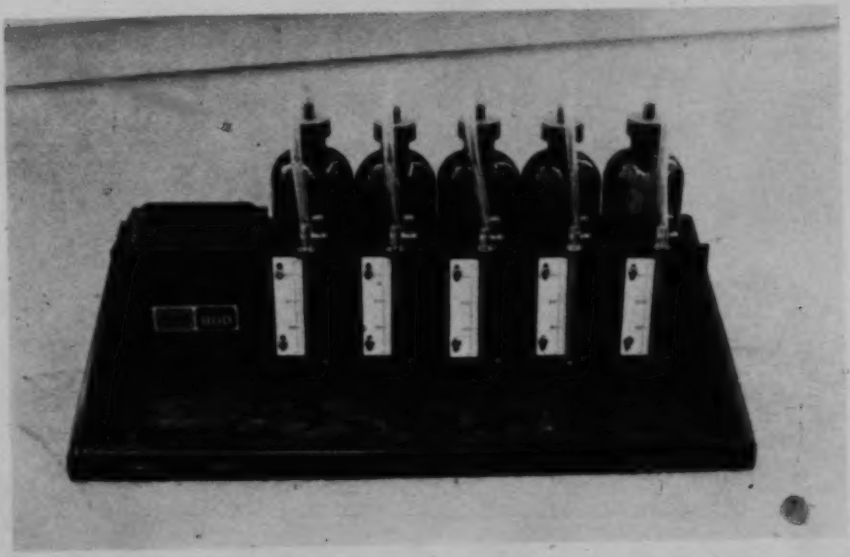

FIGURE 12: PICTURE OF THE HACH CONTINUOUS BOD ANALYSER USED TO MEASURE OXYGEN UPTAKES

Oxygen uptake rates were determined for return sludge in section 4 between June 17 and July 19. During this period section 4 operated with a return rate of 3 MIGD. The experimental procedure used to determine oxygen uptake rates was as follows:

1. A sample of return sludge was taken at the beginning of the first pass. The temperature in the tank was taken and the solids concentration in the sample was measured. DO values of the sample were also determined.
2. The sample was brought into the laboratory where 428 ml was added to each of the five BOD bottles. 428 ml of sample was chosen based on the volume-scale relations given in the apparatus' manual. The temperature of the room was controlled so that it was very near that in the tank.
3. Once all the sample bottles were filled, they were stirred for approximately five minutes and then seal cups containing KOH and the bottle caps were fixed in place. Oxygen uptake rates were recorded every half hour for a period of five hours. On several occasions uptake rates were recorded for eight hours to determine the effect of longer aeration periods.

Total solids were run on samples collected along the length of the reactivation tank. The purpose of this was to evaluate the change in solids along the tank. Dissolved oxygen profiles were also obtained for the reactivation tank.

A second study of oxygen uptake rates was carried out on section 1 between September 5 and 18. Section 1 was operated using a recycle from pass 4 during this period. With a steady return sludge flow of 3 MIGD and a recycle of 3 MIGD the detention time in the reactivation tank was 2.4 hours, one-half that of section 4 in the first study. Oxygen uptake rates of samples taken at the beginning of pass 1 were determined using the Hach method. Total and volatile total solids were run in quintiplicate on samples taken at the beginning, middle and end of the reactivation basin. Plug flow was assumed and the sample times were such that theoretically the same plug of solids was being sampled. The samples were analysed according to *Standard Methods (1971)*. Dissolved oxygen profiles were obtained for points along the tank and compared to those obtained in the normally operated sections. In this part of the study all analyses was done by the author.

4.5 Data and Analysis

The oxygen uptake rates recorded for return sludge samples from section 1 and 4 are tabulated in APPENDIX D, TABLES D1, D2 and D3. Oxygen uptake rates given in these tables represent the average of 5 values obtained for each day's sample. The average oxygen uptakes taken from TABLES D1, D2 and D3 are plotted in FIGURE 13 . FIGURE 13 shows that the average oxygen uptake rates follow similar patterns with the curve for section 1 slightly below that for section 4. The lower oxygen uptake rates exhibited by the samples from section 1 is probably due to;

1. The higher initial dissolved oxygen concentrations in the sample from the recycle, and
2. The slightly lower solids concentration of the samples from section 1.

The sharper decline in the oxygen uptake rate for section 1 between the second and third hour is probably due to the nature of solids being reaerated. Theoretically, the oxygen uptake rate curves should follow identical patterns, regardless of solids concentrations, unless the nature of the solids varies or oxygen is limiting. The sharp decline in oxygen uptake exhibited for section 1 between the second and third hour was experienced for section 4's return solids between the third and fourth hour. Both sections return solids showed a maximum oxygen uptake in the second hour of reaeration.

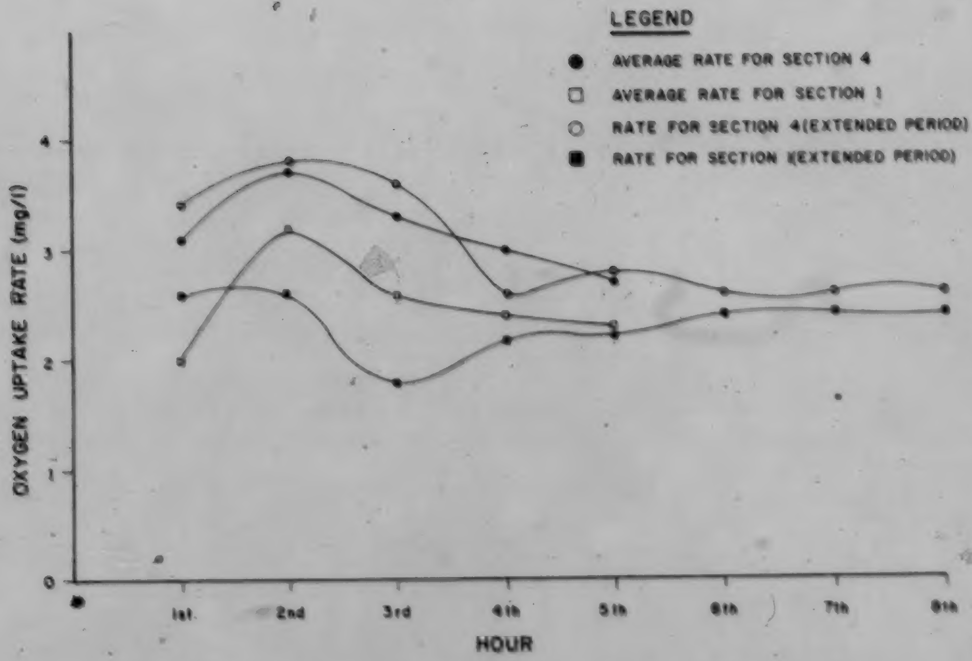

FIGURE 13: OXYGEN UPTAKE CURVES FOR RETURN SLUDGE, SECTIONS 1 AND 4, EDMONTON SEWAGE TREATMENT PLANT (a)

a) Supplementary data is contained in TABLES D1, D2 & D3

The extended oxygen uptake rate curves plotted from the data contained in TABLE D3, do not follow the average rate curves as closely as would be desired. This indicates that more extended oxygen uptake rates should have been run, especially for section 1. Both the extended oxygen uptake curves show a trend towards a level oxygen uptake after five hours of reaeration. During the oxygen uptake tests it was assumed that sufficient oxygen could be supplied so that microbial activity would not be limited due to lack of oxygen. DO concentration measured on random days and at random times showed that the dissolved oxygen concentration of the samples was maintained at .7-1 mg/l during the oxygen uptake tests.

TABLE D4 contains average total solids data collected along the reactivation tanks in sections 1 and 4 during the reaeration study. The data from TABLE D4 is plotted in FIGURE 14. FIGURE 14 shows that almost no change in total solids concentrations occurred along the first pass of either Section. This result was quite unexpected because data from the Edmonton plant showed that the difference between return sludge suspended solids and suspended solids concentrations at the end of the first pass was approximately 10%. Suspended solids concentrations determined at the same time as total solids values, between

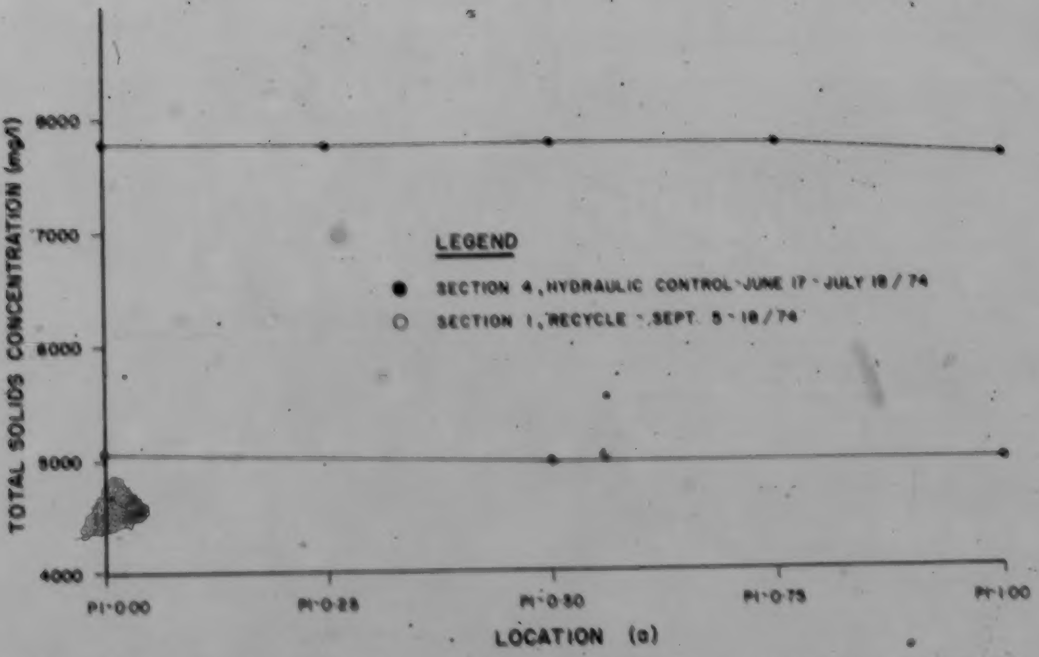

FIGURE 14: TOTAL SOLIDS CONCENTRATION IN PASS 1, SECTIONS 1 AND 4, EDMONTON SEWAGE TREATMENT PLANT (b)

a) Example - P1-0·75 = three-quarters the way along pass 1
b) Supplementary data in TABLE D4

June 17 and July 18 in Section 4, pass 1 showed that the ratio of total solids and suspended solids remained constant along the entire length of the first pass. This meant that a 10% decrease in total solids concentration should have occurred in sections 1 and 4. The explanation for this discrepancy is that the assumption of ideal plug flow is invalid. At the plant the return sludge samples are taken from the return line while the samples used for this analysis were taken from the beginning of pass 1. If the reaeration tank behaved more as acompletely mixed system this would then explain the difference in the plant's data and the values obtained during this study.

Actual dissolved oxygen concentrations, in pass 1, sections 1 and 4, measured during the same period as the oxygen uptake rates are given in TABLES 15 and 16. The data from these tables is plotted in FIGURES D3 and D4. The profiles in both figures show relatively constant concentrations of dissolved oxygen, at .3-.6 mg/l, for all sections except the one which incorporates recycle. This raises an interesting point. If, as was shown with the total solids determinations, the reaeration tank behaves as a completely mixed system why then do the DO profiles for the sections with recycle not show a constant DO concentration throughout the tank. The variation in DO values for all other sections can be accounted for by experimental error,

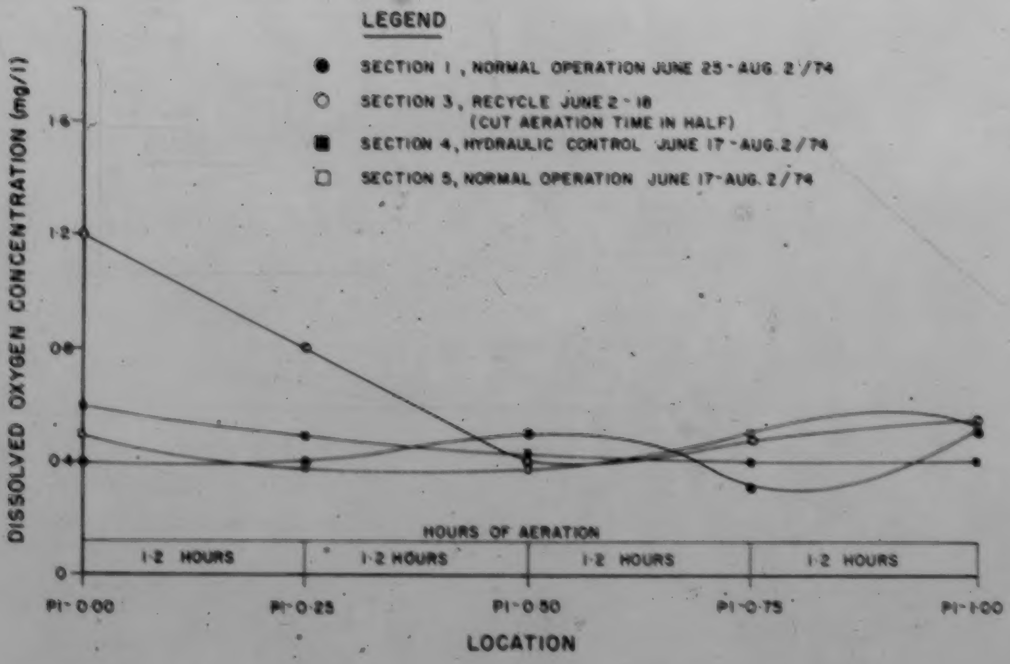

FIGURE 15: DISSOLVED OXYGEN CURVES FOR PASS 1, SECTIONS 1, 3, 4 AND 5, EDMONTON SEWAGE TREATMENT PLANT (a)

a) Supplementary data is contained in TABLE D5

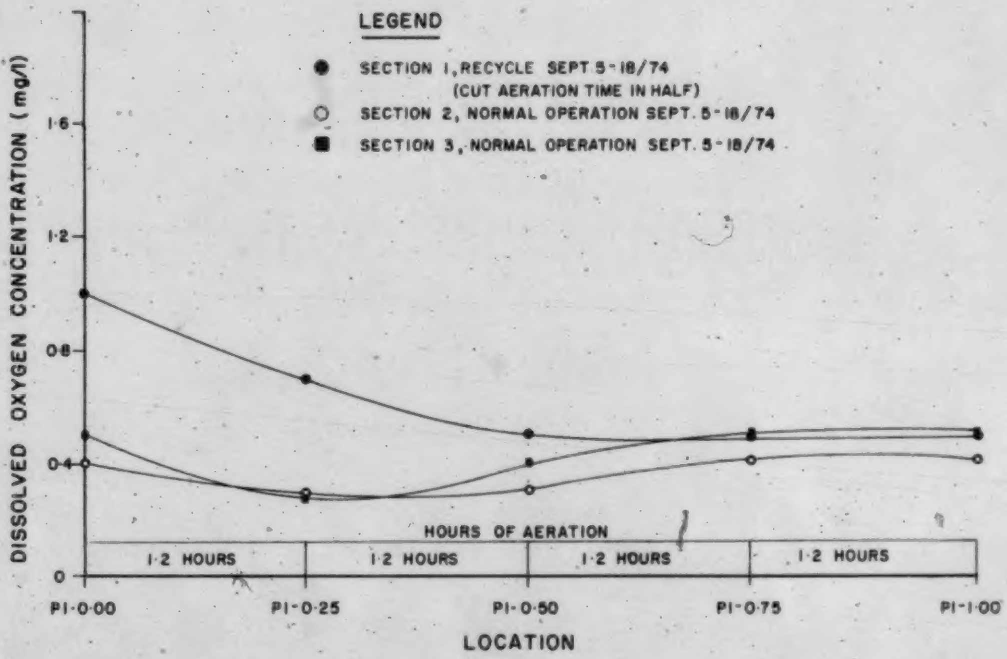

FIGURE 16: DISSOLVED OXYGEN CURVES FOR PASS 1, SECTIONS 1,2 & 3, EDMONTON SEWAGE TREATMENT PLANT

a) Supplementary data is contained in TABLE D6.

low DO analyser sensitivity and natural fluctuations but the large variations in the recycle sections are difficult to explain. A possible explanation is that oxygen demand in relation to oxygen supply, is very high and that the dissolved oxygen is utilized before it has time to thoroughly mix in the tank. This would explain the drop in the DO along the pass in the sections with recycle. It should be noted that the dissolved oxygen level in the sections with recycle, drops to the concentration of those in the other tanks quite quickly. The rapid decrease in the DO level, in sections with recycle, indicates that aeration rates are insufficient to meet the oxygen requirements. Further proof of inadequate aeration is reflected in the overall low DO concentrations along the length of all the sections. The 4.8 hour reaeration time, in sections without recycle, is excessive, based on oxygen uptake data. This extended reaeration period would normally result in high dissolved oxygen residuals, in the reaeration tank, if aeration rates were sufficient to meet demand. The DO profiles indicate however, that aeration rates are insufficient.

4.6 Conclusions and Recommendations

The conclusions and recommendations based on the data collected is as follows:

1. The total solids concentration measurements

indicate that the reaeration basin acts more as a completely mixed system than a plug flow system. To conclude that this is the case, based on this data appears valid. Further analysis, possibly a dye test however would remove any doubt. Knowing whether the system is a completely mixed or plug flow type of reactor will be very useful in developing predictive models of the process.

2. This study was carried out because it was thought that reaeration times were excessive. Based on the oxygen uptake data collected it appears that reaeration periods between 2-3 hours are necessary for return solids at the Edmonton plant. The exact reaeration period depends on the nature of the solids being reactivated. The above reaeration times however assume that sufficient oxygen is necessary to maintain a residual of approximately 1 mg/l. Because the aeration rates that are normally used at the Edmonton plant cannot supply the necessary oxygen the reaeration time must be increased. The low dissolved oxygen concentrations recorded in the sections with 4.8 hours of reaeration indicates that even this period of reaeration may be insufficient

to give optimum reactivation. The 2.4 hour period of reactivation, in sections with recycle also appears insufficient even though the recycle provides some dissolved oxygen to the system. To evaluate the performance of the reactivation basin further, samples from along the basin could be run simultaneously to determine the changes in oxygen uptake that occur as a result of aeration in the tank.

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CHAPTER V

BIOFLOCCULATION

5.1 General

At the Edmonton plant, good sludge settleability in the final settling tanks is difficult to maintain. An essential factor in the performance of an activated sludge process is the ability of the sludge to form flocs which settle rapidly and compact to yield a high-density sludge.

In this chapter the importance and the theory of bioflocculation is discussed, the control of bioflocculation in the activated sludge process described and the application of this control at the Edmonton plant studied.

5.2 Enhancing Bioflocculation in the Activated Sludge Process

5.2.1 Importance of Bioflocculation

In the activated sludge process the formation of flocs, due to agglutination of individual bacterial cells is essential if the treatment process is to operate efficiently *(Dague et al, 1972)*. The hydraulic control procedure outlined in Chapter III is a good control parameter because it gives sludges with excellent settling characteristics. One of the main criteria for determining sludge reaeration times, Chapter IV, is the settleability of the sludge. By understanding the factor(s) that affect bioflocculation it may be possible to improve treatment efficiencies by improving the settling characteristics of the sludge.

5.2.2 Theories Regarding Floc Formation

At one time it was thought that certain floc-forming bacteria were responsible for producing flocs in activated sludge. It is now known that most bacteria produce slime and form aggregates *(McKinney and Horwood, 1952; McKinney, 1956)*. Another theory proposes that protozoa, single celled organisms that feed on bacteria excreted a gelatinous slime to trap bacteria and that this slime formed the matrix of the floc *(Tenney and Stumm, 1965)*. Support for this theory, as for the theory of floc-forming bacteria, was eroded when it was found that pure cultures of most bacteria can produce flocs. Theories relating physical interparticle forces and agglutination may have some basis, but they alone are unable to explain bioflocculation *(Pavoni et al, 1972)*. The ability of microorganisms to sustain stable suspensions at or near their isoelectric point (pH 2-4) contradicts the theory that surface charge reduction is responsible for bioflocculation. The fact that negatively charged cells of bacteria can be flocculated using polyelectrolytes *(Busch and Stumm, 1968)* further indicates that zeta potential and Van der Waals forces are not significant factors in agglutination. The role of pili in bioflocculation will be discussed later in this section.

A recent theory relating poly-beta-hydroxybutyric acid (PHB) content and bioflocculation has been proposed *(Crabtree et al, 1966)*. A study using *(Z.ramigera)* one of the first floc-forming bacteria to be identified and studied did not rule out the involvement of PHB in flocculation but could find no correlation between the two *(Friedman et al, 1968)*. The current concept is that PHB is a major reserve food product which is utilized during endogenous (declining) growth *(Rouf and Stokes, 1962)*. This would explain the presence of PHB during cell agglutination since maximum flocculation occurs during the declining growth phase.

Although none of the above theories can be completely rejected each has been shown to have serious limitations. A theory relating extracellular polysaccharides and cell agglutination seems to be the most plausible *(Clark, 1958; Tenney and Stumm, 1965; Busch and Stumm, 1968; Friedman et al, 1969; Pavoni et al, 1972)*. The mecahnism is one of polymerbridging and has been described as follows by *Pavoni et.al (1972)*.

> "....bioflocculation can be viewed as the
> "result of the interaction of naturally
> "produced, high molecular weight, long chain
> "polyelectrolytes with bacterial cells in
> "such a fashion that the polyelectrolytes
> "bridge the otherwise individual cells into
> "an aggregate that will subside from suspension
> "under quiescent conditions."

From a microbiologist's standpoint there are many questions regarding the exact nature and composition of the exocellular polymers involved that require further examination. The knowledge available, however, can be used in the operation of activated sludge systems to possibly improve settling characteristics of the mixed liquor solids. The two morphological units of the cell involved in bioflocculation are:

1. The capsule, and
2. Pili

5.2.3 The Capsule and Bioflocculation

The capsule or slime layer is the outermost layer of bacteria (FIGURE 17). The slime layer is an accumulation, mainly of polysaccharides but which also contains protein, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) *(Pavoni et al, 1972)*. Slime formation is a normal result of cell metabolism and although the exact anatomical relationship of the layer to the bacterial cell is not known *(Pelczar and Reid, 1965)*,it has been shown to be the main factor in cell agglutination (Section 5.4.2).

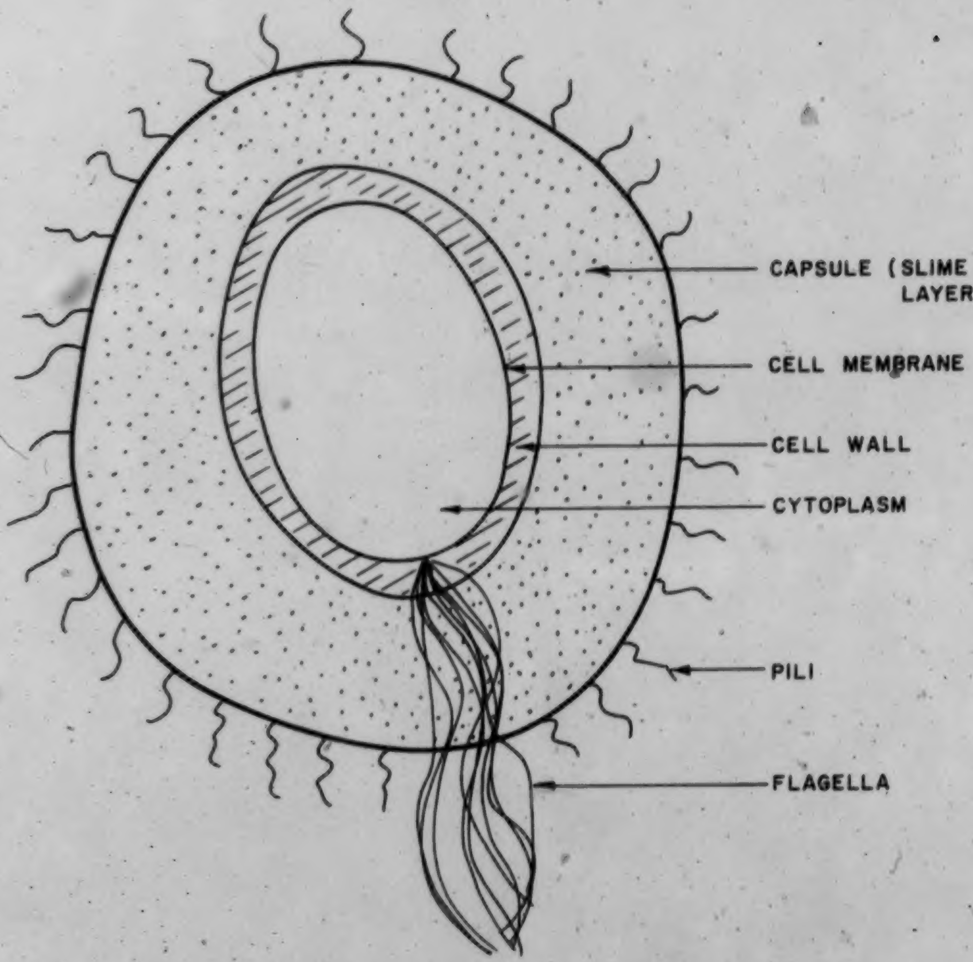
CAPSULE (SLIME LAYER)
CELL MEMBRANE
CELL WALL
CYTOPLASM
PILI
FLAGELLA

FIGURE 17: SIMPLIFIED REPRESENTATION OF A TYPICAL BACTERIAL CELL

For bacteria, the slime layer may serve as a protective covering, a storage area for food or a disposal site for waste products. The thickness of the slime layer appears to be a function of cell growth (see APPENDIX E for a description of cell growth cycle) and motility *(McKinney, 1962; Tenney and Stumm, 1965: Busch and Stumm, 1968; Pavoni et al, 1972)*. If bacteria are actively motile then the slime layer is thin due to shearing. If the microorganisms are in the declining growth phase then the slime layer is thick and bioflocculation will occur. It is therefore desirable to operate an activated sludge process such that declining growth occurs before mixed liquor enters the settling tanks.

5.2.4 Pili and Bioflocculation

Pili are filamentous appendages found on many bacteria (FIGURE 17). The property conferred to bacteria by pili is one of stickiness and cells with pili tend to adhere to one another and form flocs when grown in a media without agitation *(Stanier, 1970)*. *Friedman (1968 and 1969)* found branching pilis while studying flocs of *(Zoogloea ramigera)*. This would then indicate that pili may play a role in bioflocculation in the activated sludge process. Because pili can be mecahnically removed by agitation but rapidly form again *(Stanier 1970)*, it may be desirable in the activated sludge process to have a period of relative quiescence to allow the formation of pili, and subsequently flocs, before flow enters the settling tanks.

5.2.5 Controlling Bioflocculation in Activated Sludge

To enhance bioflocculation in an activated sludge process the organisms should be in the declining growth phase and a period of quiescence is desirable. Control of F:M ratio and reduced aeration rates are two methods of controlling the growth phase of the organisms. Low food to micro-organism ratios result in declining growth and are effective in promoting flocculation. Controlling the dissolved oxygen concentration will affect the growth phase of the sludge but unless sludge reaeration is possible this method should not be used. By limiting oxygen supply the ability of the biological mass to convert the waste organics into cell material is restricted and sludge reaeration or longer aeration periods are necessary.

The quiescent period in the settling tanks may not be of sufficient duration due to underdesign or overloading. If this is the case then utilizing part of aeration tanks as stilling basins may be possible.

Flocculation in itself does not ensure rapid settling *(Eckenfelder 1966)*. A high density floc which will settle rapidly and compact to give a dense sludge is the most desirable. If microbial growth rate is controlled, sludge reaeration time optimized and bioflocculation enhanced then high density rapid settling sludges should be maintained.

5.3 Description of the Study

To try and enhance flocculation in the activated sludge process at the Edmonton plant aeration rates were reduced along the fourth pass of section 4. By reducing aeration rates it was hoped that the organisms would go into a declining growth phase and bioflocculation would be enhanced. Reduced aeration rates also result in less turbulence in the tank. The study was performed in Section 4, during the period when hydraulic control of F:M ratio was used. By having a fixed F:M ratio the problem of variations in organic loading was eliminated. Between June 17 and July 21 aeration rates in the fourth pass of section 4 were varied and the effects of these variations were measured using dissolved oxygen profiles, settled volumes and removal efficiencies. Control of aeration rates was possible in the fourth pass of section 4 because there are 16 butterfly valves along the length of the final pass, which control the air flow into the spargers from the main distribution air line (see FIGURE 5, section 2.4.1)

FIGURE 18 is a picture of one of the butterfly valves in Section 4. Notches in a disc located below the valve handles indicate the settlings (ex. fully open, 1/2 open etc.).

During the investigation four different valve opening combinations were studied. These configurations and the periods of study are shown in TABLE IV. During the period of operation at each configuration, dissolved oxygen profiles were taken and settled volumes were determined from samples taken at five equidistant points along the pass. These were used to evaluate the effects of varied aeration rates. The actual air volume flow into the pass could not be measured because air flows as measured at the plant include air for both the third and fourth passes. To try and eliminate some of the variables resulting from not knowing the aeration rates into the fourth pass the following procedure was followed:

1. Dissolved oxygen profiles and settled volumes were taken at approximately the same time each day (2 p.m.)
2. Aeration rates to the third and fourth passes were held fairly constant at a rate of 5-6 million cubic feet per day (MCFD) during the early afternoon period.

FIGURE 18: PICTURE SHOWING THE TOP VIEW OF A BUTTERFLY VALVE IN THE FULLY OPEN POSITION, PASS 4, SECTION 4

If the aeration rate to the third and fourth pass was 5 MCFD it was observed that it did not matter whether all the butterfly valves in the fourth pass were closed or not the air flow still remained at 5 MCFD. By changing the valve settings in the fourth pass, aeration rates to this pass were changed but the over-all aeration rate to passes 3 and 4 did not change significantly.

Settled volumes were determined using the procedure in *Standard Methods (1971)* and dissolved oxygen profiles were determined using the Ionics dissolved oxygen analyser. Treatment efficiency data for Section 4 during the study period was obtained from plant personnel and is shown in TABLE A3.

5.4 Data and Analysis

The settled volumes obtained for various butterfly valve settings, are given in TABLES F1, F2, F3, F4 and F5. The average settled volumes for each valve setting are given in each table and plotted together in FIGURE 19. FIGURE 19 shows that a decrease in the settled volumes occurred between June 17 and June 30. This decrease was probably due to the improved operation of the treatment section and cannot be attributed to the variations in valve settings. The June 17-23 period gave

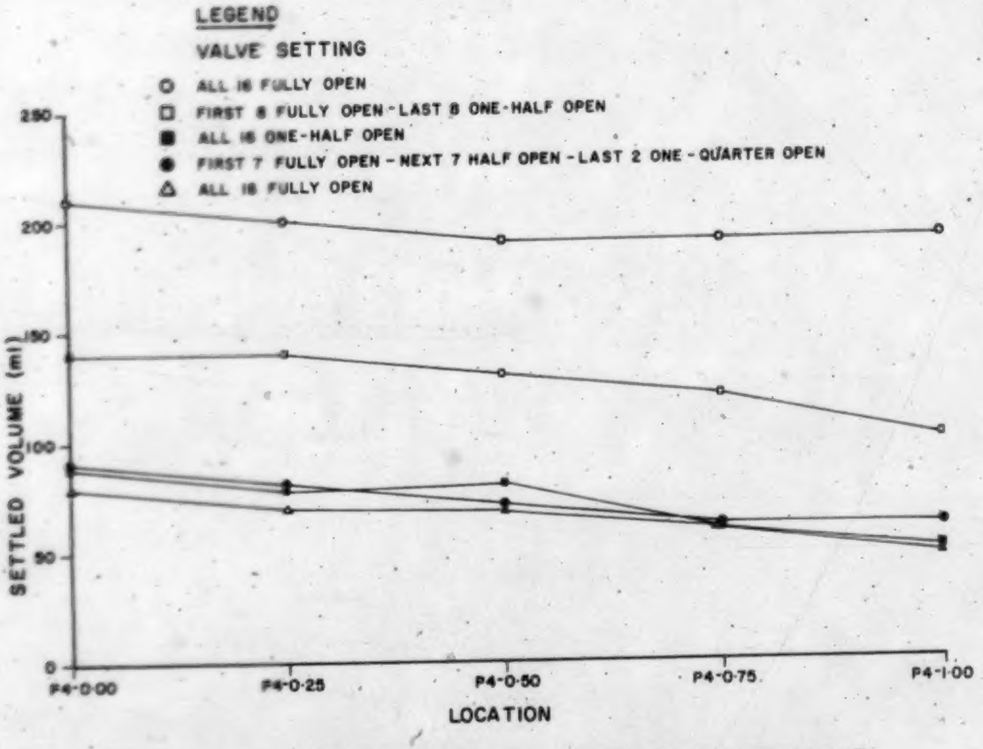

FIGURE 19: AVERAGE SETTLED VOLUMES FOR VARIOUS AIR VALVE SETTINGS PASS 4, SECTION 4, EDMONTON SEWAGE TREATMENT PLANT

a) Supplementary data is contained in TABLES F1 - F5 the highest settled volumes and the July 15-21 period gave the lowest settled volume.Yet during both periods all the butterfly valves were fully open. The three different valve settings between July 2 and July 21 afforded a wide range in valve settings and yet no significant difference in settled volumes was seen. Based on the settled volume data, it would appear that very little difference in sludge settleability occurred at the aeration rates and valve settings used in this study.

TABLE IV gives operating and performance data for section 4, for the various air valve settings. The per cent removal figures should not be considered too significant because of the short duration of each test period. It is interesting to note though, that at reduced aeration rates, solids removal increased and that at the minimum aeration rate solids removal was highest. No trends in BOD removal and aeration rates are apparent but another interesting point is the fact that per cent BOD removal was the lowest when aeration rates were the lowest.

Dissolved oxygen concentrations taken along the fourth pass, section 4, at approximately the same time as settled volumes were determined and are given in TABLES

TABLE IV: AIR VALVE SETTING, OPERATING AND PERFORMANCE DATA FOR SECTION 4

EDMONTON SEWAGE TREATMENT PLANT JUNE 17 - JULY 21, 1974

				% removal		settled volume
Date	Valves[a]	Setting	MLSS (mg/1)[b]	BOD (mg/1)	SS (mg/1)	end of 4th pass (ml)[b]
June 17 - 23	1-16	fully open	1630	80	80	200
June 24 - 30	1- 8	fully open	1570	75	83	110
	9-16	one-half open				
July 2 - 7	1-16	one-half open	1430	73	88	60
July 8 - 14	1- 7	fully open	1640	83	82	60
	8-14	one-half open				
	15-16	one-quarter open				
July 15 - 21	1- 6	fully open	1640	76	82	60

---

[a] Valves are number 1 to 16 starting at the beginning of pass 4 (16 valves in the pass)

[b] The values given are average values for the particular periods

F6, F7, F8, F9 and F10. The average dissolved oxygen concentrations, for each valve setting are given in each table and plotted together in FIGURE 20. The profiles in FIGURE 20 show that higher aeration rates (i.e. more air valves fully open) gave higher DO residuals. By changing the valve settings to the half open position along the last half of the pass, lower residuals than those obtained when the valves were fully open, resulted. An observation made, during observation of dissolved oxygen concentrations, was that changing an air valve setting say from fully open to one-half open, did not seem to make a great difference in the aeration rate. This was a visual observation made based on the turbulence in the tank at various air valve settings. It appears then that by changing an air valve setting from the fully open to one-half open position only results in a 10-20% decrease in the aeration rate. This fact helps to explain the dissolved oxygen profile obtained for the period when all the air valves in the pass were one-half open. This profile is very similar to the other profiles for the first half of the pass. If aeration rates are not decreased greatly, by shutting the air valve to the one-half open position, then all the profiles could be expected to be quite similar. The overall low dissolved oxygen levels in the first half of the pass indicate that

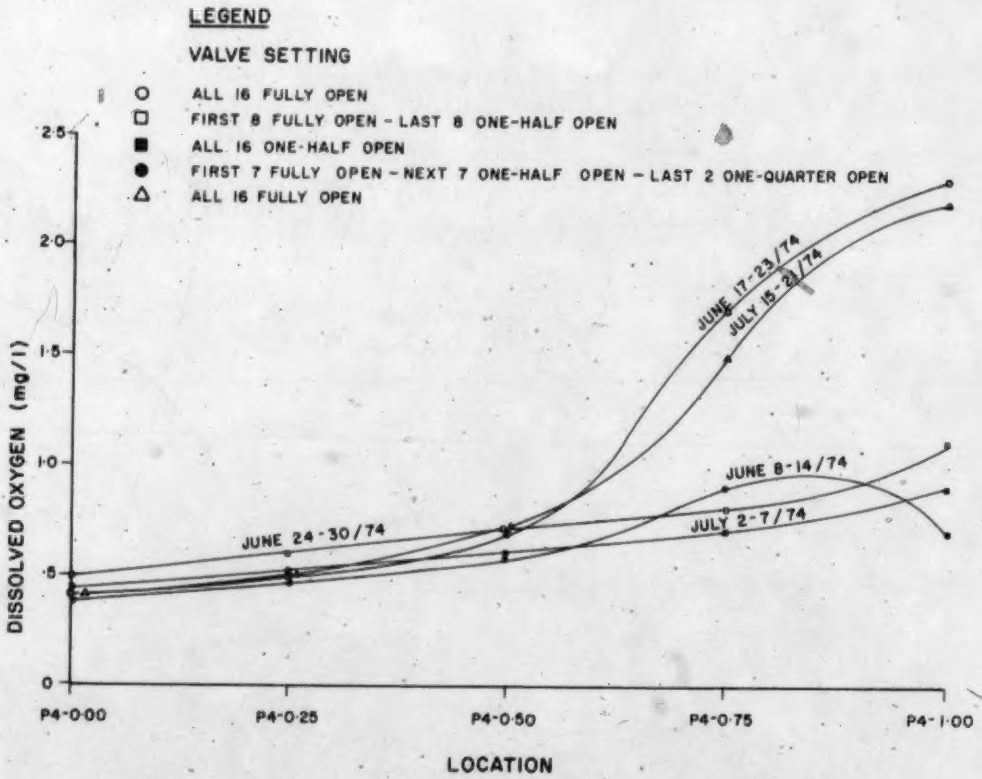

FIGURE 20: DISSOLVED OXYGEN PROFILES FOR VARIOUS AIR VALVE SETTINGS, PASS 4, SECTION 4, EDMONTON SEWAGE TREATMENT PLANT (a).

a) Supplementary data is contained in TABLES F6 - F10 the aeration rates were insufficient to meet oxygen demands. At the half way point along the tank dissolved oxygen residuals began to increase. The dissolved oxygen values obtained in the last half of the pass indicate that the valve settings in all cases, resulted in increasing residuals and it is therefore doubtful that the organisms were at any time in the declining growth phase due to insufficient oxygen. The profiles taken when all valves were fully open show that oxygen levels along the beginning of the pass are low but that at the end of the pass they are high.

5.5 Summary

The various valve settings used to control aeration rates and the settled volume and dissolved oxygen data collected during each setting yield no conclusive results regarding aeration rates and bioflocculation. The fact that aeration rates at the various valve settings could not be measured greatly restricted the interpretation of the data. The data collected nevertheless yielded some very useful information. It was shown by the DO profiles that aeration rates of 5-6 MCFD are insufficient to maintain the desired DO concentrations along the beginning of the fourth pass. The profiles also showed that, when aeration rates are sufficient to meet the oxygen requirements, the butterfly valves can effectively control the dissolved oxygen residual in the tanks. Settled volume data showed that there is a decrease in the settled volume of the mixed liquor as it flows along pass 4 but no change in settled volumes was obtained at the various valve settings.

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This chapter is a summary of the conclusions and recommendations made in previous chapters. Some new recommendations as to the direction future work in the area of activated sludge operation could take are also presented.

Based on the data collected for this study the following conclusions can be drawn:

1. The dissolved oxygen concentration in the aeration tanks is insufficient and as a result limits microbial activity and decreases the efficiency of the process.
2. Insufficient oxygen in the reaeration pass of the aeration tanks means that detention time in the pass must be increased thus decreasing the amount of tank volume that could be used for substrate removal from the primary effluent.
3. The butterfly valves in the fourth pass of each section can be used to control

aeration but because the relationship between air flows and valve settings is not linear it is necessary to operate the valves near the closed position if effective air flow reduction is to be obtained. Because this was not done by the author during the study, no effective evaluation regarding aeration rates and bioflocculation could be made.

4. The study showed that the assumption of plug flow in the tanks is invalid and the determine the exact flow characteristics in the system a dye study will be required.

The following are recommendations for future studies:

1. The coefficient Y and Kd should be derived for the activated sludge system. Rather than using BOD as a measure of substrate removal TOC should be used.
2. The chemical, physical and biological characteristics of the biological flocs in the settling tanks should be determined and related to process operation. This should be helpful in relating SVI,

bioflocculation and operation of the process.

3. It may also be possible to characterize the diurinal and daily fluctuations in substrate quantity and quality and set up a feed forward control system for the activated sludge process.
4. The end result of the above work would be to develop a predictative model of the system which could be used to optimize the process and could aid in developing future process designs.

APPENDIX A

OPERATIONAL DATA FOR SECONDARY TREATMENT SECTIONS AT THE EDMONTON SEWAGE TREATMENT PLANT

TABLE A1: OPERATIONAL DATA FOR SECTION 1
EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION
(JUNE TO AUGUST, 1974)[a]

Date	Secondary Influent			Return Sludge		Waste[b] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[c]
	Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
June 25	7.8	150	132	2.5	8156	.00	1366	23	14	8.9
26	8.1	149	179	2.4	11514	.10	2286	10	19	7.6
27	9.2	54	196	2.4	11900	.20	2350	68	20	3.5
28	9.0	69	160	2.3	8696	.15	2320	14	8	5.2
29	11.5	97	134	2.3	12822	.15	2402	12	11	4.3
30	11.2	74	61	2.3	12000	.00	2200	3	9	5.0
July 1	10.6	55	37	2.4	11606	.00	1908	10	15	3.6
2	11.2	61	165	2.4	10854	.15	2044	10	10	4.0
3	11.5	72	174	2.4	10838	.15	1872	10	16	4.7
4	11.6	64	81	2.4	10842	.15	1844	14	19	5.2
5	13.3	84	113	3.0	10406	.15	2040	19	16	5.7
6	13.5	97	195	3.0	10850	.15	1964	13	5	4.6
7	12.9	90	92	3.1	11000	.15	2000	16	12	4.8
8	11.8	70	52	3.0	11036	.00	2114	18	18	4.5
9	13.3	144	202	3.0	11854	.15	2208	18	28	10.7
10	13.8	137	313	3.0	11766	.15	2250	19	7	10.0
11	12.1	118	102	3.2	12662	.15	2510	20	19	11.4
12	14.4	68	402	3.2	14004	.15	2562	10	12	9.2
13	14.5	44	69	3.1	17104	.15	2826	14	22	6.8
14	14.5	55	153	2.9	17000	.15	2400	10	20	6.5
15	14.4	28	52	3.0	17244	.10	1884	12	32	7.5
16	14.1	73	121	3.2	14288	.10	1834	10	16	6.8
17	13.1	56	66	3.0	12168	.30	3054	12	9	7.7
18	13.1	81	81	2.9	10042	.30	2406	16	22	9.3
19	12.6	48	62	3.0	9906	.30	1736	16	17	10.6
20	11.0	109	79	2.8	7464	.20	1640	16	1	10.5
21	12.0	71	97	2.9	7400	.20	1500	17	24	8.2

.....cont'd

TABLE A1: cont'd.....

Date	Secondary Influent			Return Sludge		Waste[b] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[c]
	Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
July 22	11.8	57	73	3.6	7400	.00	1382	21	21	7.8
23	12.6	93	99	2.8	7630	.15	2028	13	17	10.1
24	12.5	101	102	2.9	7868	.15	1710	10	22	13.0
25	12.7	111	73	2.8	7776	.15	1270	16	17	13.6
26	12.3	126	138	2.8	8926	.00	1452	34	17	12.5
27	12.4	79	93	3.0	10638	.00	2114	28	25	12.5
28	11.1	110	40	2.9	11300	.00	2300	28	11	11.1
29	10.5	116	36	2.9	12016	.00	2456	30	7	11.8
30	10.9	92	81	2.8	13394	.20	2934	28	54	14.8
31	12.0	101	77	2.9	13004	.20	2826	12	16	12.1
Aug. 1	12.8	113	64	2.9	12188	.20	2580	17	19	13.3
2	12.7	123	91	2.9	11344	.20	2290	18	19	16.8

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[a] All BOD and SS data is the average for 24 hour composite samples taken at 1 MIGD, secondary influent, flow intervals. Flow data is the average daily.

[b] SS for waste sludge = SS for return sludge

[c] Aeration rate data is the average of three readings taken each day.

TABLE A2: OPERATIONAL DATA FOR SECTION 3
EDMONTON SEWAGE TREATMENT PLANT - RECYCLE [a]
(JUNE TO AUGUST, 1974)[b]

Date	Secondary Influent			Return Sludge		Waste[c] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[d]
	Q MIGD	BOD mg/l	SS mg/l	Q MIGD	SS mg/l	Q MIGD	SS mg/l	BOD mg/l	SS mg/l	MCFD
June 17	12.7	102	110	3.3	8142	.00	1636	14	24	6.2
18	12.8	116	63	3.3	8126	.20	1736	24	22	7.0
19	11.4	116	238	3.3	8120	.00	1774	41	22	7.3
20	12.2	137	110	3.3	8596	.20	1869	29	25	7.3
21	11.5	145	47	3.3	7800	.20	2164	9	18	9.7
22	11.0	153	70	3.3	8672	.20	1992	5	21	9.7
23	11.8	79	118	3.3	9000	.00	2100	8	16	7.6
24	12.1	50	86	3.3	9074	.00	2258	24	14	7.5
25	12.2	150	132	3.3	8865	.00	2538	46	11	9.2
26	15.3	149	179	3.3	7980	.20	2042	29	23	9.1
27	14.4	54	196	3.3	9978	.15	2308	16	10	4.2
28	14.2	69	160	3.3	12704	.00	2644	18	10	5.8
29	13.3	97	134	3.3	11688	.15	2740	15	14	4.6
30	12.9	74	61	3.3	11000	.15	2600	5	13	4.6
July 1	11.9	55	37	3.3	11586	.00	2700	14	13	3.9
2	12.4	61	165	3.3	10538	.15	2460	18	12	4.0
3	12.7	72	174	3.3	13012	.15	2514	22	14	4.9
4	12.8	64	81	3.3	12652	.15	3156	39	16	5.9
5	14.7	84	113	3.3	15924	.25	3118	30	24	6.3
6	14.9	97	195	3.3	13192	.25	3080	16	4	5.3
7	14.2	90	92	3.3	16000	.25	3000	16	17	5.1
8	13.0	70	52	3.3	19160	.00	3062	20	12	4.8
9	14.6	144	202	3.3	14442	.25	3250	26	22	9.7
10	15.1	137	313	3.3	13094	.25	2958	21	10	12.7
11	13.3	118	102	3.2	16318	.25	3152	24	13	12.8
12	15.8	68	402	3.2	19000	.25	3182	6	8	10.1
13	16.0	44	69	3.1	21526	.25	3534	8	22	6.9

.....cont'd

TABLE A2: cont'd......

Date	Secondary Influent			Return Sludge		Waste[c] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[d]
	Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
July 14	15.9	55	153	3.0	24516	.25	2946	7	6	11.4
15	15.8	28	52	3.0	20000	.25	2900	12	20	8.7
16	15.5	73	121	3.4	15500	.22	2852	18	22	9.3
17	14.4	56	66	3.5	19288	.16	3238	19	13	10.7
18	14.4	81	81	3.4	13416	.24	2754	18	6	11.4

[a] From July 2 to July 18, 3 MIGD of mixed liquor was pumped from the end of the 4th Pass to the beginning of the 1st pass.

[b] All BOD and SS data is the average for 24 hour composite samples taken at IMIGD, secondary inlufent, flow intervals. Flow data is the average daily.

[c] SS for waste sludge = SS for return sludge

[d] Aeration rate data is the average of three readings taken each day

TABLE A3: OPERATIONAL DATA FOR SECTION 4
EDMONTON SEWAGE TREATMENT PLANT - HYDRAULIC CONTROL[a]
(JUNE TO AUGUST , 1974)[b]

Date	Secondary Influent			Return Sludge		Waste[c] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[d]
	Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
June 17	12.7	102	110	3.0	8626	.10	1636	16	23	6.5
18	12.8	116	63	3.0	8656	.12	1668	22	30	7.6
19	11.4	116	238	3.0	8134	.10	1602	29	46	7.4
20	12.2	137	110	3.0	7858	.10	1512	23	26	8.0
21	11.5	145	47	3.0	7104	.10	1860	22	9	9.6
22	11.0	152	70	3.0	6982	.12	1640	28	5	9.6
23	11.8	79	118	3.0	6600	.12	1500	26	12	7.2
24	12.1	50	86	3.0	6354	.10	1338	24	16	6.7
25	12.2	150	132	3.0	6156	.10	1300	19	17	8.9
26	15.3	149	179	3.0	5620	.10	1226	23	13	8.9
27	14.4	54	196	3.0	7538	.10	1782	9	15	4.0
28	14.2	69	160	3.0	8696	.12	1840	14	29	5.3
29	13.3	97	134	3.0	8394	.12	1826	18	10	4.9
30	12.9	74	61	3.0	8000	.12	1700	30	32	4.2
July 1	11.9	55	37	3.0	6356	.11	1498	18	18	3.5
2	12.4	61	165	3.0	5936	.10	1360	38	26	3.1
3	12.7	72	174	3.0	8712	.10	1262	14	6	5.0
4	12.8	64	81	3.0	6506	.10	1436	20	14	5.4
5	14.7	84	113	3.0	6860	.11	1610	14	26	6.4
6	14.9	97	195	3.0	7386	.12	1480	15	3	5.3
7	14.2	90	92	3.0	6800	.12	1400	15	13	5.0
8	13.0	70	52	3.0	6241	.12	1352	18	20	4.5
9	14.6	144	202	3.0	6646	.10	1456	18	28	8.8
10	15.1	137	313	3.0	7204	.11	1474	20	11	11.5
11	13.3	118	102	3.0	7568	.11	1536	13	17	12.5
12	15.8	68	402	3.0	9174	.11	1710	6	13	9.2
13	16.0	44	69	3.0	11682	.11	2088	14	24	5.4

.....cont'd

TABLE A3: cont'd.....

Date	Secondary Influent			Return Sludge		Waste Sludge[c]	Mixed Liquor	Secondary Effluent		Total Aeration Rate[d]
	Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
July 14	15.9	55	153	3.0	11092	.11	1834	6	18	6.9
15	15.8	28	52	3.0	10000	.10	1900	12	18	7.4
16	15.5	73	121	3.0	9064	.10	2002	12	15	12.7
17	14.4	56	66	3.0	7670	.10	1568	11	11	12.5
18	14.4	81	81	3.0	6810	.10	1812	15	12	12.7
19	13.8	48	62	3.0	6786	.10	1442	12	13	14.3
20	12.0	109	79	3.0	6568	.12	1486	10	2	14.2
21	13.3	71	97	3.0	6200	.10	1300	32	23	11.6
22	12.9	57	73	2.0	5884	.00	1200	23	20	8.4
23	13.9	93	99	3.0	5874	.10	1062	13	18	11.6
24	13.8	101	102	3.0	6192	.10	1120	12	25	11.3
25	13.9	111	73	3.0	5138	.10	1046	12	3	12.2
26	13.5	126	138	3.0	4994	.10	886	16	7	12.9
27	13.6	79	93	3.0	4822	.10	918	12	16	13.3
28	12.2	110	40	3.0	4900	.10	1100	22	9	10.8
29	11.5	116	36	3.0	5044	.10	1238	24	15	10.1
30	11.9	92	81	3.0	5350	.12	1100	14	23	10.1
31	13.3	101	77	3.0	3799	.12	1038	10	12	12.7
Aug. 1	12.8	113	64	3.0	4986	.10	1046	17	21	10.7
2	12.7	123	91	3.0	4636	.10	1148	19	36	9.9

[a] Hydraulic control of F:M ratio was maintained by maintaining a return rate of 3.0 MIGD and a waste rate of .10-.12 MIGD.

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TABLE A3: cont'd.....

[b] All BOD and SS data is the average for 24 hour composite samples taken at 1 MIGD, secondary influent, flow intervals. Flow data is the average daily.

[c] SS for waste sludge = SS for return sludge

[d] Aeration rate data is the average of three readings taken each day.

TABLE A4: OPERATIONAL DATA FOR SECTION 5
EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERTION
(JUNE TO AUGUST, 1974)[a]

Date		Secondary Influent			Return Sludge		Waste[b] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[c]
		Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
June	17	12.7	102	110	3.3	10508	.30	2140	18	20	6.5
	18	12.8	116	63	3.3	10312	.30	2204	19	15	7.6
	19	11.4	116	238	3.3	10232	.30	2198	30	34	7.5
	20	12.2	137	110	3.3	9940	.30	2126	17	23	7.6
	21	11.5	145	47	3.3	9220	.30	2432	20	20	9.6
	22	11.0	152	70	3.3	7570	.30	2152	18	22	9.6
	23	11.8	79	118	3.3	8500	.00	2100	16	15	7.7
	24	12.1	50	86	3.3	9528	.00	2084	16	23	7.7
	25	12.2	150	132	3.3	9366	.25	2000	15	40	9.5
	26	15.3	149	179	3.3	8900	.20	2000	10	35	10.0
	27	14.4	54	196	3.3	10758	.15	2188	37	133	4.9
	28	14.2	69	160	3.3	12740	.00	2424	12	27	6.6
	29	13.3	97	134	3.3	13238	.15	2940	19	30	5.3
	30	12.9	74	61	3.3	13000	.15	3006	25	32	5.3
July	1	11.9	55	37	3.3	13298	.00	3006	24	36	4.4
	2	11.2	61	165	3.3	12482	.30	2960	25	66	4.3
	3	10.9	72	174	3.3	11606	.50	2722	14	19	5.0
	4	10.4	64	81	3.4	9540	.50	2428	20	31	5.9
	5	12.0	84	113	3.3	9956	.15	2250	13	6	5.5
	6	12.2	97	195	3.3	11232	.15	2220	19	6	4.7
	7	11.6	90	92	3.4	12000	.15	2500	36	34	4.5
	8	10.6	70	52	3.3	12432	.00	2726	40	24	5.2
	9	12.0	144	202	3.3	13146	.15	3010	18	37	9.9
	10	12.3	137	313	3.3	13938	.15	2970	38	40	12.6
	11	12.4	118	102	3.2	14430	.30	3212	41	110	11.9
	12	12.2	68	402	3.2	13012	.60	2968	12	26	9.4
	13	12.4	44	69	3.6	12700	.60	2088	8	30	6.6

.....cont'd

TABLE A4: cont'd.....

Date	Secondary Influent			Return Sludge		Waste[b] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[c]
	Q MIGD	BOD mg/1	SS mg/1	Q MIGD	SS mg/1	Q MIGD	SS mg/1	BOD mg/1	SS mg/1	MCFD
July 14	12.2	55	153	3.4	12600	.30	2800	4	27	7.2
15	12.2	28	52	3.4	12606	.00	3544	9	30	7.1
16	12.0	73	121	2.9	10108	.45	2588	10	9	10.1
17	14.4	56	66	3.0	9390	.30	1954	16	16	10.2
18	14.4	81	81	3.4	6086	.30	1356	22	16	9.6
19	13.8	48	62	3.3	7884	.30	1724	10	15	9.1
20	12.0	109	79	3.2	7674	.15	1876	14	8	9.1
21	13.3	71	97	3.4	8400	.20	2000	32	23	9.9
22	12.9	57	73	3.2	9078	.00	2048	15	21	9.1
23	13.9	93	99	3.3	9820	.15	2126	8	6	10.7
24	13.8	101	102	3.4	13522	.15	2110	6	22	13.6
25	13.9	111	73	3.3	12076	.15	2164	13	12	14.9
26	13.5	126	138	3.3	11428	.15	2284	20	21	13.0
27	13.6	79	93	3.4	11544	.15	2198	46	59	12.5
28	12.2	110	40	3.4	11800	.20	2400	37	27	11.7
29	11.5	116	36	3.4	11982	.00	2716	28	13	11.5
30	11.9	92	81	3.2	11548	.34	2420	17	30	11.8
31	13.3	101	77	2.8	10574	.30	2160	12	19	14.7
Aug. 1	12.8	113	64	2.8	9692	.25	2060	17	26	12.3
2	12.7	123	91	2.8	10200	.20	2034	17	18	11.6

[a] All BOD and SS data is the average for 24 hour composite samples taken at 1 MIGD, secondary influent, flow intervals. Flow data is the average daily.

.....cont'd

TABLE A4: cont'd.....

[b] SS for waste sludge = SS for return sludge

[c] Aeration rate data is the average of three readings taken each day.

TABLE A5: OPERATING DATA FOR SECTION 1
EDMONTON SEWAGE TREATMENT PLANT - RECYCLE[a]
(SEPTEMBER, 1974)[b]

Date	Secondary Influent			Return Sludge		Waste[c] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[d]
	Q[*] MIGD	BOD mg/l	SS mg/l	Q MIGD	SS mg/l	Q MIGD	SS mg/l	BOD mg/l	SS mg/l	MCFD
Sept. 5	7.0	148	69	3.0	9624	.10	1918	23	4	15.2
6	6.7	150	141	3.0	10144	.10	2208	26	38	15.0
7	6.6	120	70	3.0	7544	.11	2354	63	133	13.9
8	6.6	101	64	3.0	7800	.15	2200	13	6	12.8
9	6.4	99	58	3.0	8006	.15	2020	14	6	12.6
10	6.9	70	74	3.0	8336	.15	1810	22	10	11.8
11	7.0	282	225	3.0	10118	.10	2000	16	42	10.7
12	7.0	84	83	3.0	11212	.10	2246	64	14	7.6
13	6.1	106	94	3.0	12388	.15	2264	65	20	12.4
14	7.6	131	26	3.2	11080	.15	2334	14	4	19.4
15	7.1	113	80	3.0	10000	.15	2200	15	10	19.0
16	7.2	130	118	3.0	8416	.15	1972	28	8	11.1
17	6.6	158	143	3.0	9652	.15	2036	27	22	11.1
18	6.7	198	134	3.0	7886	.15	1802	42	5	12.8

[a] Throughout the above period 3 MIGD of mixed liquor was pumped from the end of the 4th pass to the beginning of the first.

[b] All BOD and SS data is the average for 24 hour composite samples taken at 1 MIGD, secondary influent, flow intervals. Flow data is the average daily.

[c] SS for waste sludge = SS for return sludge

[d] Aeration rate date is the average of three readings taken each day.

[*] Flow rate into the section is an estimate because only 12 gates to the section were open.

APPENDIX B

MCRT WASTE RATE CALCULATIONS AND WASTE RATE CURVES FOR THE EDMONTON PROCESS

WASTE RATE CALCULATIONS

If the values of Y and Kd are known and a desired range for F:M ratio is established then the desired MCRT is fixed according to the equation:

$$1/\theta_c = YU - Kd$$

The values for U, Y and Kd reported by *Jenkins and Garrison (1968), Walker (1971) and Burchett and Tchobanoglous (1974)* are:

$Y = 0.5-0.6$
$Kd = .04-.05$
$U = .2-.5$

Using these values a range for θ_c of 6-18 days is established. By using values of θ_c that lie in this range the desired waste rates are determined in the following way:

1. Return sludge rate is determined.
2. Detention time in reactivation basin is calculated.
3. A sewage influent flow is chosen.
4. Detention time in aeration basin and settling tanks is determined.
5. The number of passes the sludge makes through the system is calculated.
6. The desired MCRT is chosen.
7. The waste rate required is calculated.

Example Calculation:

Say return sludge rate = 3.5 MIGD

detention time in reactivation basin =

$$\frac{93{,}000 \text{ cu.ft}}{3.5 \text{ MIGD}} = 4 \text{ hours}$$

for sewage flow = 10 MIGD detention time in

aeration and settling tanks =

$$\frac{279{,}000 \text{ cu.ft}}{13.5 \text{ MIGD}} + \frac{660{,}000 \text{ gal}}{13.5 \text{ MIGD}} = 3.1+.1.8 = 4.28 \text{ hrs}$$

Therefore the number of passes the sludge makes through the system each day =

$$\frac{24}{4 + 4.28} = 2.9$$

for MCRT = 18 days

Waste rate =

$$\frac{3.5}{18 \times 2.9} = .067 \text{ MIGD}$$

Calculations were done for:

1. Return rates (MIGD) - 3.5, 3.25, 3.0, 2.75, 2.5.
2. Influent flows (MIGD) - 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.
3. MCRT (days) - 6, 8, 10, 12, 14, 16, 18.

The information obtained from the above calculations is presented graphically in FIGURES B1-B5.

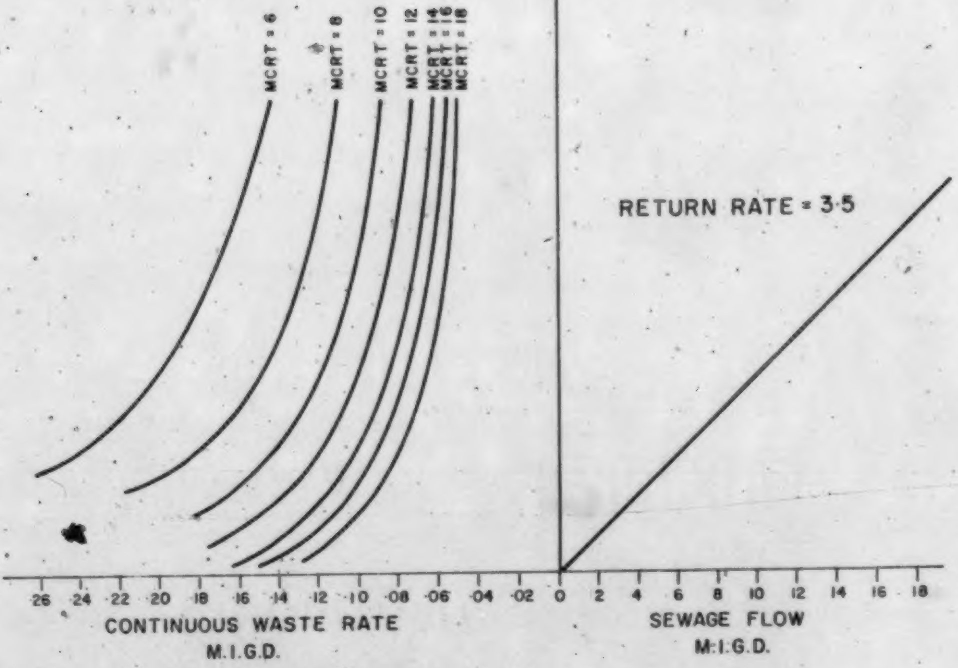


FIGURE B1: WASTE RATE CURVES FOR RETURN RATE 3·5 MIGD

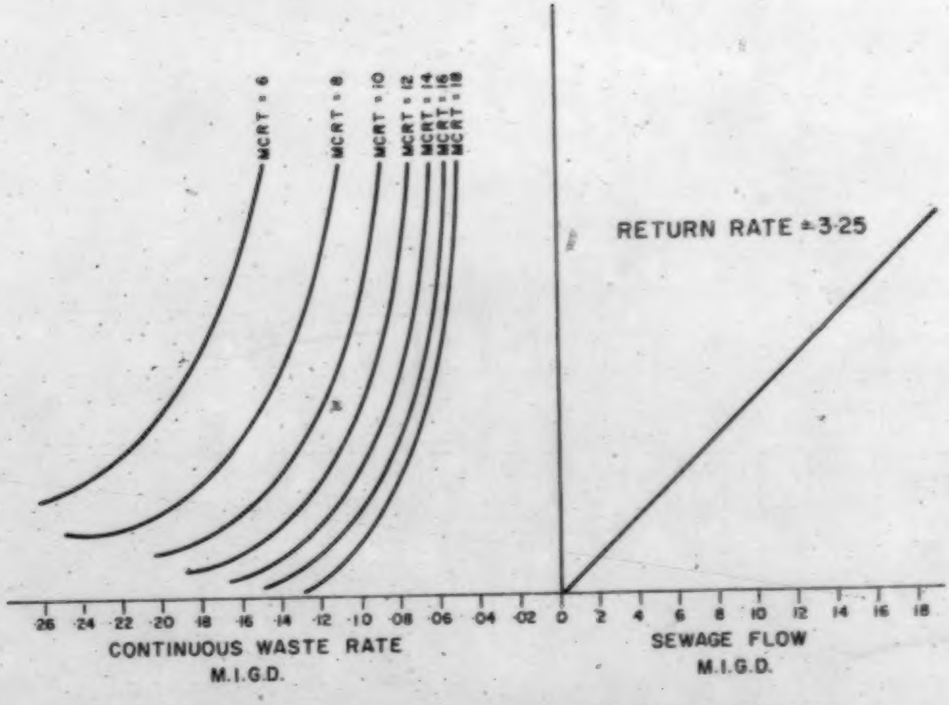


FIGURE B2: WASTE RATE CURVES FOR RETURN RATE 3·25 MIGD

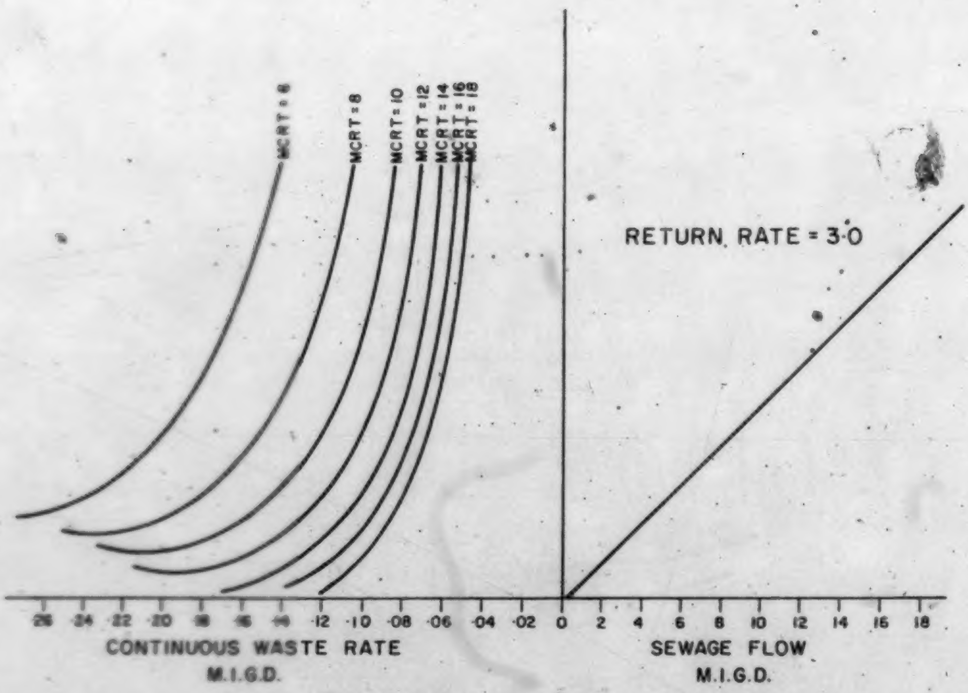


FIGURE B3: WASTE RATE CURVES FOR RETURN RATE 3·0 MIGD

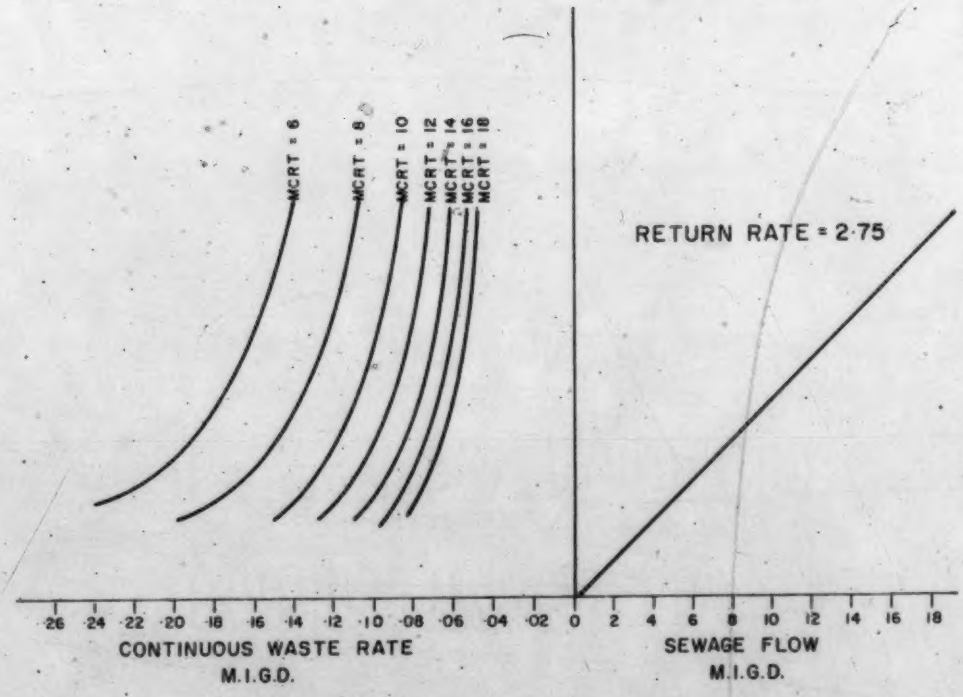


FIGURE B4: WASTE RATE CURVES FOR RETURN RATE 2·75 MIGD

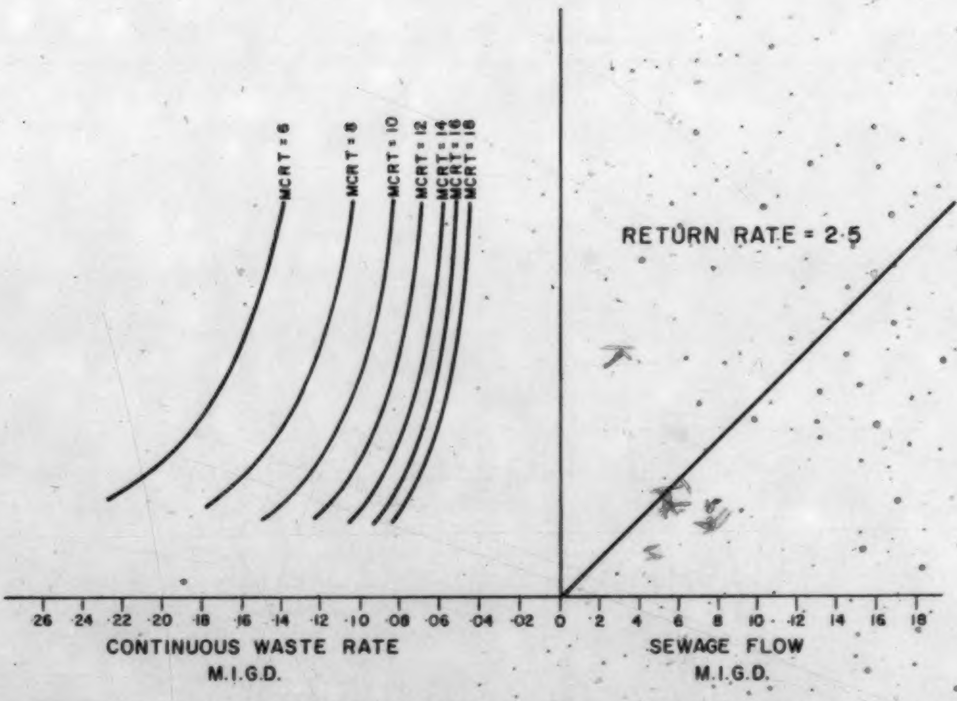


FIGURE B5: WASTE RATE CURVES FOR RETURN RATE 2·5 MIDG

APPENDIX C

COMPARISONS BETWEEN SECTION 4's EFFLUENT BOD AND SUSPENDED SOLIDS CONCENTRATION AND THE BOD AND SUSPENDED SOLIDS IN SECTIONS 1, 3 AND 5's EFFLUENT

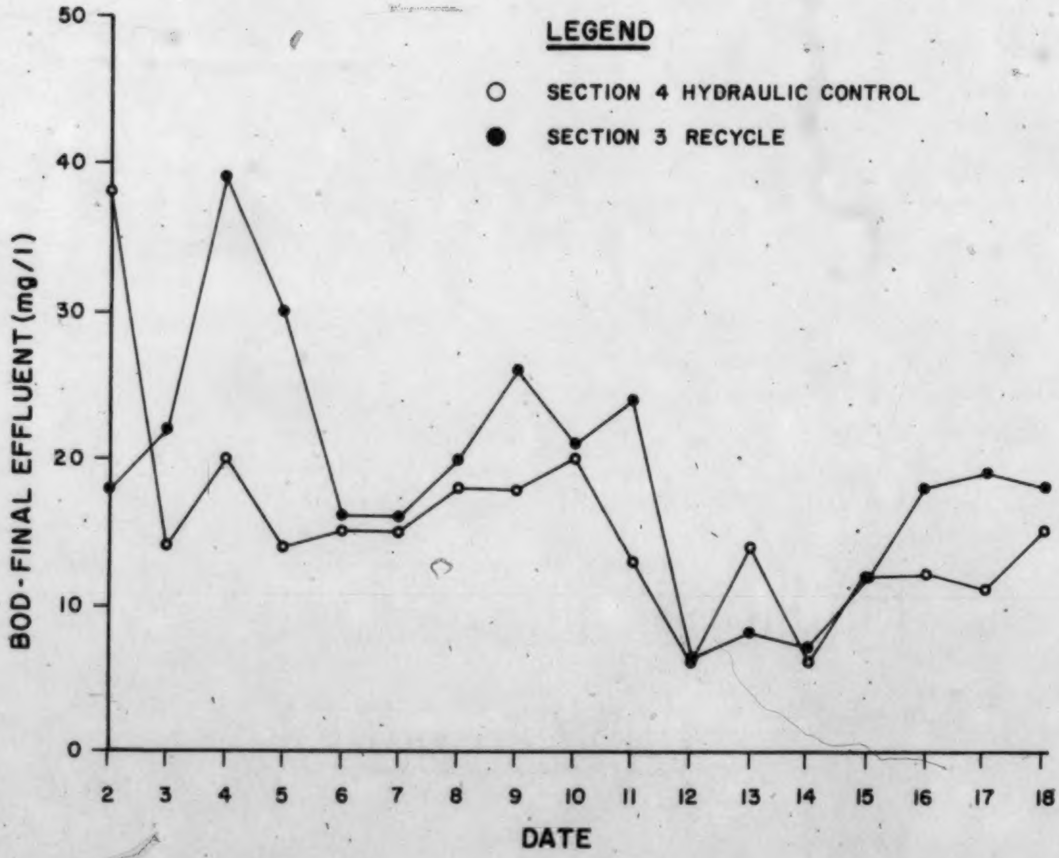


FIGURE C1 : COMPARISON OF BOD IN FINAL EFFLUENTS, SECTIONS 3 & 4, EDMONTON SEWAGE TREATMENT PLANT a)

a) Supplementary data is contained in TABLES A2 and A3.

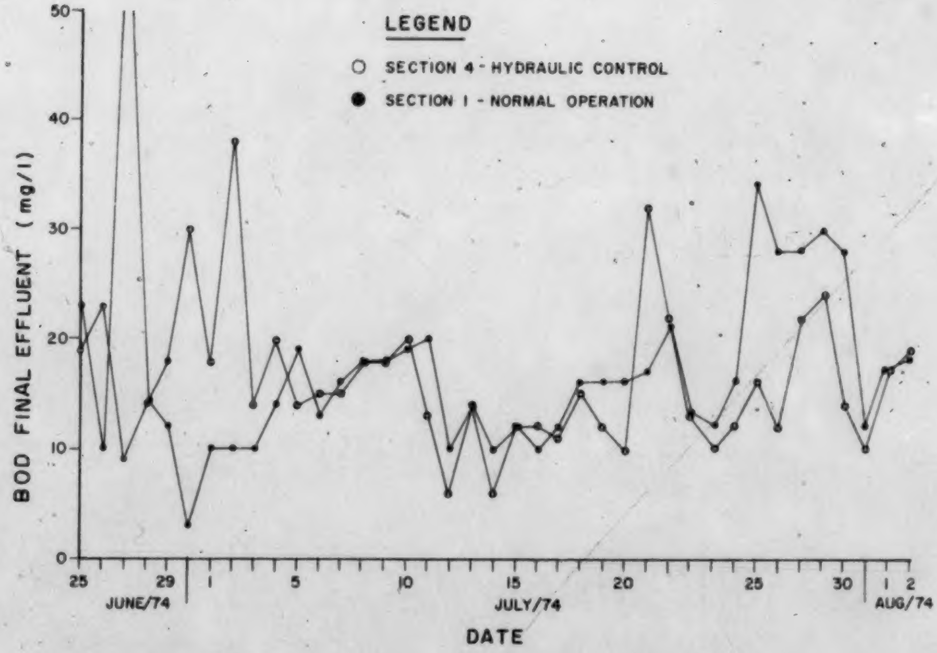


FIGURE C2: COMPARISON OF BOD IN FINAL EFFLUENTS SECTIONS 1 AND 4, EDMONTON SEWAGE TREATMENT PLANT (a)

a) Supplementary data contained in TABLES A1 and A3

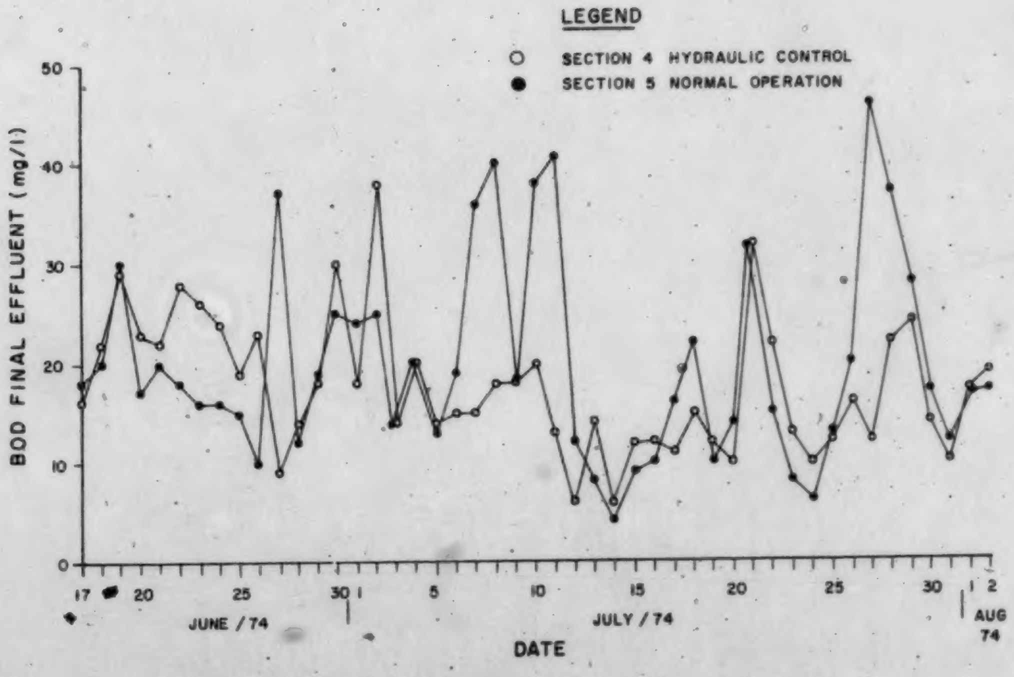


FIGURE C3: COMPARISON OF BOD IN FINAL EFFLUENTS, SECTIONS 4 AND 5, EDMONTON SEWAGE TREATMENT PLANT [(a)]

a) Supplementary data is contained in TABLES A3 and A4

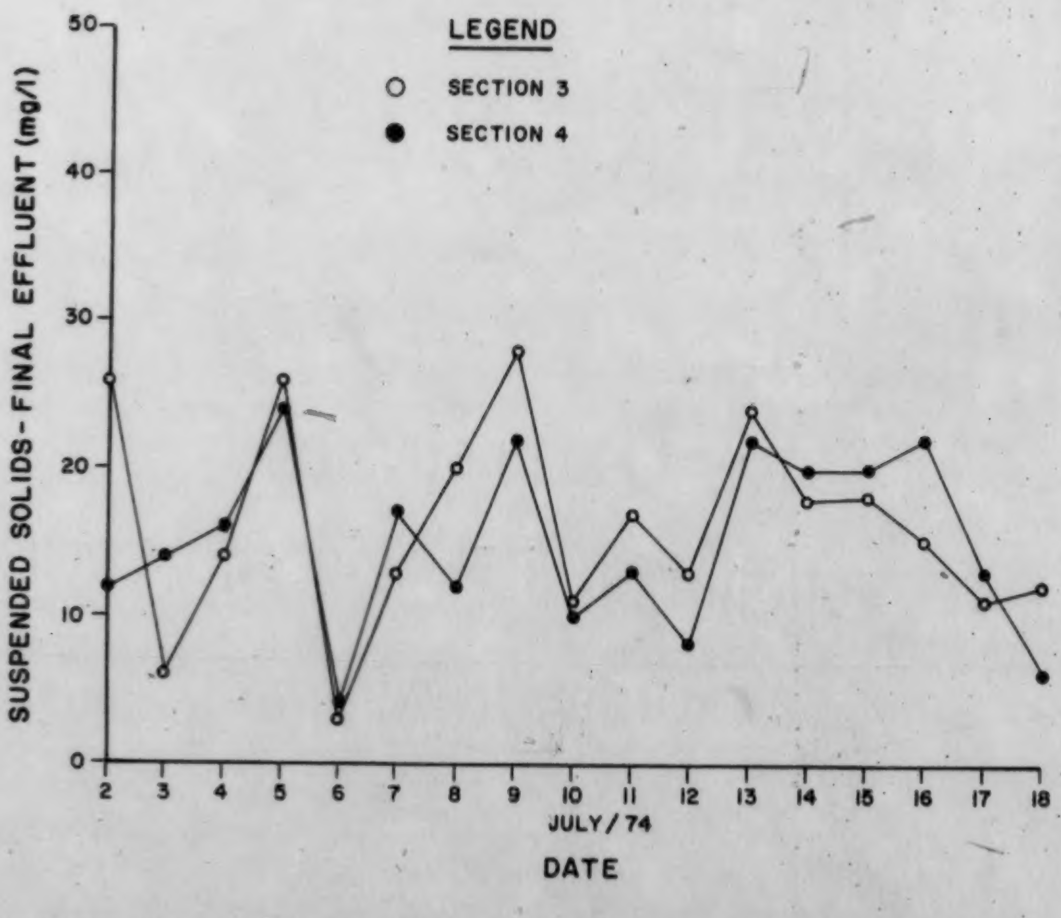
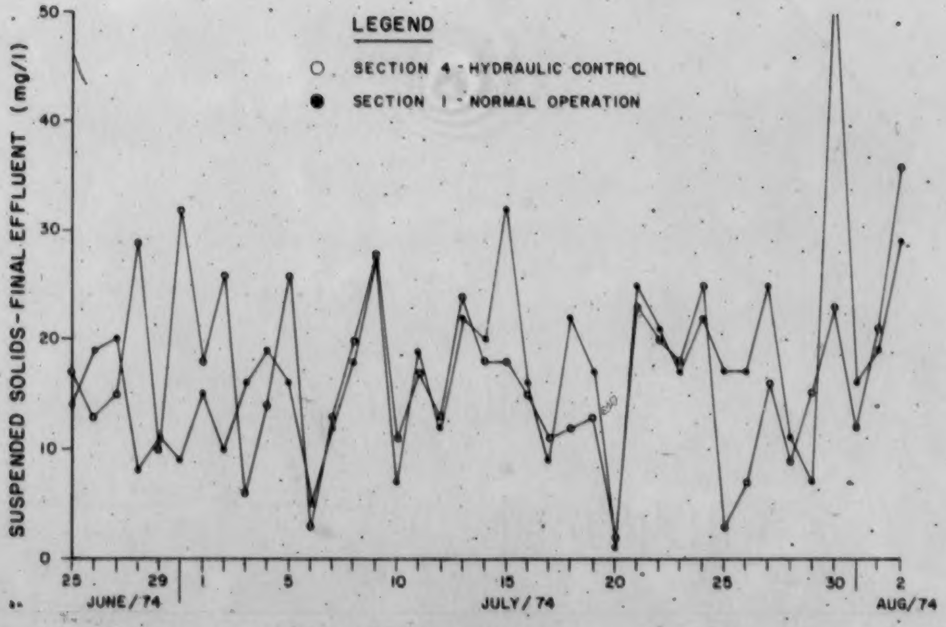


FIGURE C4: COMPARISON OF SUSPENDED SOLIDS IN EFFLUENTS, SECTIONS 3 & 4, EDMONTON SEWAGE TREATMENT PLANT (a)

a) Supplementary data contained in TABLES A 2 and A 3



DATE

FIGURE C5: COMPARISON OF SUSPENDED SOLIDS IN FINAL EFFLUENTS(a)
SECTIONS 1 AND 4, EDMONTON SEWAGE TREATMENT PLANT
a) Supplementary data is contained in TABLES A1 and A3

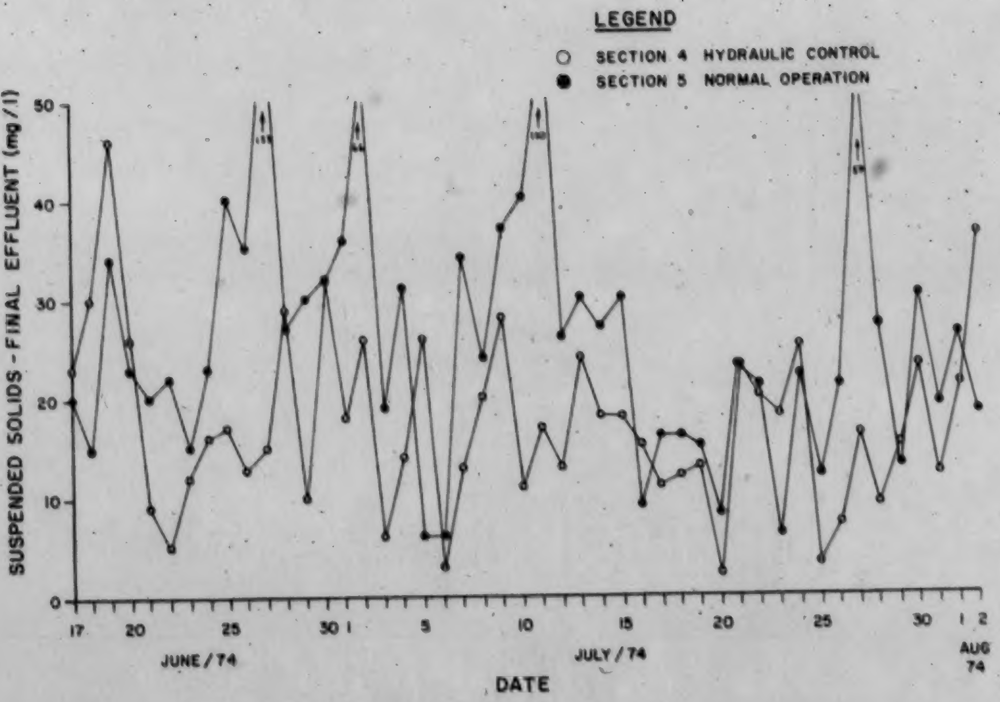


FIGURE C6: COMPARISON OF SUSPENDED SOLIDS IN FINAL EFFLUENTS, SECTIONS 4 & 5, EDMONTON SEWAGE TREATMENT PLANT (a)

a) Supplementary data is contained in TABLES A3 and A4

APPENDIX D

OXYGEN UPTAKE DATA, SOLIDS DATA AND DISSOLVED OXYGEN DATA FOR REAERATION STUDY

TABLE D1: OXYGEN UPTAKE RATES FOR SAMPLES TAKEN AT THE START OF PASS 1 SECTION 4 - EDMONTON SEWAGE TREATMENT PLANT [a]

Date	RSTS (mg/1)	1st hr	Oxygen Uptake (mg/1) 2nd hr	3rd hr	4th hr	5th hr
June 17	9430	2.9	4.1	3.7	3.4	3.1
June 18	7674	4.0	4.5	3.1	3.4	2.4
June 19	8298	4.0	4.4	4.2	4.6	2.7
June 20	7209	3.7	4.5	4.3	3.6	3.3
June 21	7182	4.4	3.8	3.7	2.9	3.0
June 25	5894	4.0	4.4	3.7	3.4	2.1
June 27	8546	1.1	1.6	2.2	2.6	2.5
July 2	5758	4.1	3.5	3.2	2.7	2.7
July 3	5966	2.4	3.9	4.0	2.9	2.6
July 4	6024	3.7	3.4	3.2	2.6	2.5
July 5	6847	3.0	4.4	3.9	2.3	2.5
July 8	4884	3.4	4.0	3.7	3.3	2.8
July 9	7144	2.7	3.9	3.4	3.8	3.1
July 15	8604	2.6	2.9	2.4	2.2	2.6
July 16	7821	1.7	3.2	3.1	2.3	2.4
July 17	6858	3.0	3.5	3.0	2.6	2.8
July 18	6284	2.9	3.3	3.1	2.6	3.0
July 19	6421	3.8	2.7	2.6	3.0	2.6
ave.	6994	3.1	3.7	3.3	3.0	2.7

---

[a] During this period Section 4 was controlled using an hydraulic control method. Oxygen uptake rates given are an average of 5 values obtained for each sample.

TABLE D2: OXYGEN UPTAKE RATES FOR SAMPLES TAKEN AT START OF PASS 1, SECTION 1 - EDMONTON SEWAGE TREATMENT PLANT [a]

Date	RSTS (mg/l)[b]	1st hr	Oxygen Uptake (mg/l)[c] 2nd hr	3rd hr	4th hr	5th hr
Sept 5	5700	2.4	3.5	2.9	2.1	2.3
Sept 6	5736	2.3	3.2	2.8	2.6	2.5
Sept 9	4200	2.5	2.7	1.7	2.2	2.0
Sept 10	4720	1.0	3.4	2.6	2.4	2.1
Sept 11	5280	1.5	3.3	2.8	2.8	2.0
Sept 12	6020	1.8	3.3	2.8	2.4	2.5
Sept 13	5740	2.6	3.5	2.7	2.2	2.2
Sept 16	4400	2.6	2.5	2.0	2.1	2.5
Sept 17	4435	2.7	3.7	3.1	2.5	3.3
Sept 18	4375	1.0	2.7	2.9	2.4	1.6
ave.	5060	2.0	3.2	2.6	2.4	2.3

[a] Section 1 was operated with a recycle of 3 MIGD. The recycle was take from the end of the 4th pass and added to the beginning of the 1st pass.

[b] The RSTS value was taken after the return sludge and recycle had mixed.

[c] Oxygen uptake rates are an average of 5 values obtained for each sample.

TABLE D3: OXYGEN UPTAKE RATES FOR AN EXTENDED PERIOD ON RETURN SLUDGE SAMPLES, SECTIONS 1 AND 4 EDMONTON SEWAGE TREATMENT PLANT [a]

				Oxygen Uptake (mg/l)				
Date	1st hr	2nd hr	3rd hr	4th hr	5th hr	6th hr	7th hr	8th hr
June 21	4.4	3.8	3.7	2.9	3.0	2.8	2.7	2.7
July 5	3.0	4.4	3.0	2.3	2.5	2.4	2.5	2.4
July 18	2.9	3.3	3.1	2.6	3.0	2.6	2.6	2.6
average	3.4	3.8	3.6	2.6	2.8	2.6	2.6	2.6
Sept. 9	2.5	2.7	1.7	2.2	2.0	2.3	2.2	2.4
Sept.16	2.6	2.6	2.0	2.1	2.5	2.5	2.6	2.4
average	2.6	2.6	1.8	2.2	2.2	2.4	2.4	2.4

---

[a] Oxygen uptake rates for above samples are shown for the first 5 hours in TABLES D1 and D2

TABLE D4: AVERAGE TOTAL SOLIDS DATA FOR THE REACTIVATION TANKS IN SECTIONS 1 AND 4

EDMONTON SEWAGE TREATMENT PLANT

	Total Solids (mg/l)	
Location	Section 1[a]	Section 4[b]
P1-0.00	5050	7780
P1-0.25		7752
P1-0.50	4991	7772
P1-0.75		7727
P1-1.00	4963	7609

[a] Values given are an average of 10 samples collected between September 5 and 18. Each sample collected was run in quintiplicate and the average of the 5 values used as value of the total solids at that location on that day. Samples were collected assuming plug flow and theoretically the same plug of solids was sampled at each location. Section 1 was operated using recycle during this period.

[b] Values given are an average of 18 values collected between June 17 and July 18. Samples were collected assuming plug flow and theoretically the same plug of solids was sampled at each location. Section 1 was controlled to a fixed F:M ratio during this period.

TABLE D5: AVERAGE DISSOLVED OXYGEN DATA FOR SECTIONS 1,3,4 AND 5 EDMONTON SEWAGE TREATMENT PLANT JUNE 17 - AUGUST 2, 1974 [a]

	Section			
Location[b]	1[c]	3[d]	4[e]	5[c]
P1-0.00	0.4	1.2	0.6	0.5
P1-0.25	0.4	0.8	0.5	0.4
P1-0.50	0.5	0.4	0.4	0.4
P1-0.75	0.3	0.5	0.4	0.5
P1-1.00	0.5	0.5	0.4	0.5
P2-0.25	0.4	0.4	0.3	0.4
P2-0.50	0.3	0.5	0.6	0.5
P2-0.75	0.6	0.4	0.5	0.5
P2-1.00	0.5	0.5	0.4	0.6
P3-0.25	0.7	0.6	0.5	0.5
P3-0.50	0.6	0.5	0.3	0.4
P3-0.75	0.4	0.3	0.3	0.3
P4-0.00	0.5	0.3	f	0.4
P4-0.25	0.5	0.3	f	0.4
P4-0.50	0.6	0.6	f	0.7
P4-0.75	1.0	1.2	f	1.3
P4-1.00	1.6	2.0	f	1.9

---

[a] Average dissolved oxygen data was obtained by averaging values from 63 dissolved oxygen profiles taken between June 17 and August 2.

[b] Locations referred to are as in the example:

Location P2-0.25

P2 refers to pass 2
0.25 refers to a point that is one quarter of the pass length from the start of the particular pass.

[c] These sections were normally operated.

TABLE D5: cont'd......

[d] Data used was collected between July 3 and July 19 when section was operated with a recycle of 3 MIGD

[e] Section 4 was controlled to a fixed F:M ratio during this period

[f] Values for pass 4, section 4 are given in TABLES because air valve settings were varied during most of the period.

TABLE D6: AVERAGE DISSOLVED OXYGEN DATA FOR PASS 1, SECTIONS 1, 2 AND 3
EDMONTON SEWAGE TREATMENT PLANT SEPTEMBER 5 - 18, 1974[a]

	Section		
Location	1[b]	2[c]	3[c]
P1-0.00	1.0	0.4	0.5
P1-0.25	0.7	0.3	0.3
P1-0.50	0.5	0.3	0.4
P1-0.75	0.5	0.4	0.5
P1-1.00	0.5	0.4	0.5

[a] Average dissolved oxygen data was obtained by averaging values from 15 dissolved oxygen profiles taken between September 5 and 18.

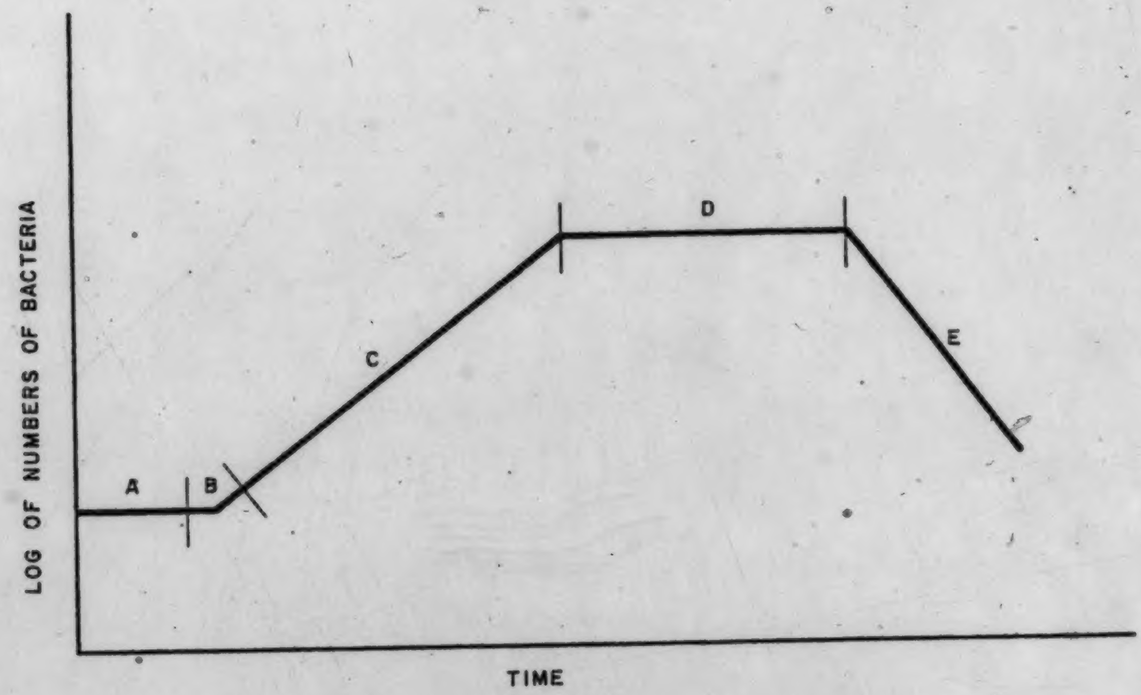
[b] Section 1 operated with 3 MIGD of recycle.

[c] Sections normally operated.

APPENDIX E

GROWTH CYCLE OF BACTERIA

To illustrate growth cycle of bacteria it is desirable to examine a theoretical growth curve obtained using a pure culture. In a mixed biological system such as that found in the activated sludge process the growth curve would be a function of the individual growth curves for each organism within the system.



Typical growth curve A, Lag phase; B, accelerated growth phase; C, log (logarithmic), or exponential phase; D, stationary phase; E, death or decline phase.

Lag Phase - during this phase, the bacteria introduced into a new media are very active but little or no cell division occurs. The organisms are synthesizing the compounds necessary to utilize the organic food source within the media.

Accelerated Growth Phase - this is a transition phase which results because not all organisms begin reproduction at the same time.

The Logarithmic Phase - during this phase the bacteria are reproducing at a constant rate and, therefore, utilization of the available substrate is maximal.

The Stationary Phase - The transition from log growth to stationary growth is gradual and is a result of exhaustion of substrate or a change in the physical and chemical environment which retards growth.

The Death Phase - following stationary growth the expiration rate of the bacteria begin to exceed the rate of reproduction and the number of viable cells begins to decline. The rate of decline may be a function of the particular organism.

The above growth curve is that which would be obtained in a batch reactor. In a completely mixed continuous flow reactor operating at a steady state condition the growth rate is constant and is equal to the dilution rate. There is a wide range of dilution rates over which steady state conditions will exist. However, at some upper range the dilution rate will exceed the growth rate and a 'washout' of the cells occurs. At very low dilution rates cell growth ceases. By controlling the dilution rate (i.e. cell residence time) it is therefore possible to control the growth rate and maintain steady state conditions. This is the procedure that was used in Chapter III.

The difference between batch growth cultures and continuous growth cultures is that batch growth gives changing cell concentrations with time whereas continuous growth gives a constant concentration of cells over a period of time. It is important to note that for each point on the batch growth curve a corresponding point exists for the operation of a continuous culture at the same substrate concentration and growth rate.

APPENDIX F

SETTLED VOLUMES AND DISSOLVED OXYGEN DATA FOR SECTION 4, PASS 4, JUNE 17 - JULY 21, 1974

TABLE F1: SETTLED VOLUMES (ml) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JUNE 17 - 23, 1974[b]

	DATE					
Location	June 17	June 18	June 19	June 20	June 21	Average
P4-0.00	210	200	200	250	190	210
P4-0.25	190	200	180	230	180	200
P4-0.50	180	190	180	240	180	190
P4-0.75	180	190	170	240	180	190
P4-1.00	180	180	160	250	190	190

[a] Valve settings were such that all sixteen air valves were fully open

[b] 1 litre samples were taken in graduated cylinders and allowed to settle for 30 minutes, values given are millilitres of sludge settled after 30 minutes. Samples were taken at approximately the same time as the DO data was collected.

[c] Locations referred to are as in the example:

Location P4-0.25

P4 refers to pass 4
0.25 refers to a point that is one-quarter of the pass length from the beginning of the pass.

TABLE F2: SETTLED VOLUMES (ml) FOR SECTION 4, PASS 4[a]

EDMONTON SEWAGE TREATMENT PLANT JUNE 24 - 30, 1974

	DATE			
Location	June 24	June 27	June 28	Average
P4-0.00	140	130	150	140
P4-0.25	140	140	130	140
P4-0.50	130	130	130	130
P4-0.75	120	120	110	120
P4-1.00	120	90	100	100

[a] Valve settings were such that the first eight air valves in the pass were fully open and the last eight were one-half open.

TABLE F3: SETTLED VOLUMES (ml) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JULY 2 - 7, 1974

	DATE				
Location	July 2	July 3	July 4	July 5	Average
P4-0.00	90	80	90	100	90
P4-0.25	70	80	80	80	80
P4-0.50	70	80	80	80	80
P4-0.75	60	60	60	70	60
P4-1.00	50	50	50	60	50

[a] Valve settings were such that all sixteen air valves were one-half open.

TABLE F4: SETTLED VOLUMES (ml) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JULY 8 - 14, 1974

	DATE				
Location	July 8	July 9	July 11	July 12	Average
P4-0.00	80	90	100	90	90
P4-0.25	80	90	80	80	80
P4-0.50	70	70	70	60	70
P4-0.75	60	70	60	70	60
P4-1.00	50	50	60	60	60

[a] Valve settings were such that the first seven air valves in the pass were fully open, the next seven were one-half open and the final two were one-quarter open.

TABLE F5: SETTLED VOLUMES (ml) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JULY 15 - 21, 1974

	DATE				
Location	July 15	July 16	July 17	July 18	Average
P4-0.00	80	70	90	80	80
P4-0.25	60	70	70	70	70
P4-0.50	60	70	70	70	70
P4-0.75	50	60	60	60	60
P4-1.00	50	50	50	50	50

[a] Valve settings were such that all sixteen air valves were fully open.

TABLE F6: DISSOLVED OXYGEN (mg/1) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JUNE 17 - 23, 174

Location[b]	DATE					
	June 17	June 18	June 19	June 20	June 21	Average
P4-0.00	0.4	0.5	0.5	0.4	0.2	0.4
P4-0.25	0.6	0.4	0.6	0.6	0.3	0.5
P4-0.50	0.8	0.5	0.8	1.0	0.6	0.7
P4-0.75	1.9	1.8	1.7	1.8	1.3	1.7
P4-1.00	2.5	2.2	2.8	2.3	1.7	2.3

[a] Valve settings were such that all sixteen valves were fully open, measurements were taken in the early afternoon on each date and air flow to 3rd and 4th passes was 5-6 MCFD.

[b] Locations referred to are as in the example:

Location P4-0.75

P4 refers to pass 4
0.75 refers to a point three quarters of the pass length from the beginning of the pass.

TABLE F7: DISSOLVED OXYGEN (mg/1) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JUNE 24 - 30, 1974

Location[b]	DATE			
	June 24	June 27	June 28	Average
P4-0.00	0.6	0.4	0.4	0.5
P4-0.25	0.7	0.6	0.5	0.6
P4-0.50	0.7	0.8	0.7	0.7
P4-0.75	0.8	0.8	0.9	0.8
P4-1.00	1.1	1.3	1.2	1.1

[a] Valve settings were such that first eight butterfly valves in the pass were fully open and last eight were one-half open, measurements were taken in the early afternoon on each date and air flows to 3rd and 4th passes was 5-6 MCFD.

[b] Locations referred to are as in the example:

Location P4-0.75

P4 refers to pass 4
0.75 refers to a point three quarters of the pass length from the beginning of the pass.

TABLE F8: DISSOLVED OXYGEN (mg/1) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JULY 2 - 7, 1974

	DATE				
Location[b]	July 2	July 3	July 4	July 5	Average
P4-0.00	0.3	0.4	0.2	0.5	0.4
P4-0.25	0.5	0.4	0.4	0.6	0.5
P4-0.50	0.6	0.6	0.5	0.7	0.6
P4-0.75	0.6	0.8	0.7	0.8	0.7
P4-1.00	0.7	0.9	1.0	1.0	0.9

[a] Valve settings were such that all sixteen valves were one-half open, measurements were taken in the early afternoon on each date and air flow to 3rd and 4th passes was 5-6 MCFD.

[b] Locations referred to are as in the example:

Location P4-0.75

P4 refers to pass 4
0.75 refers to a point three quarters of the pass length from the beginning of the pass.

TABLE F9: DISSOLVED OXYGEN (mg/l) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JULY 8 - 14, 1974

	DATE				
Location	July 8	July 9	July 11	July 12	Average
P4-0.00	0.4	0.4	0.5	0.5	0.4
P4-0.25	0.4	0.5	0.5	0.5	0.5
P4-0.50	0.6	0.7	0.6	0.6	0.6
P4-0.75	0.8	0.7	0.9	1.1	0.9
P4-1.00	0.6	0.3	0.8	1.0	0.7

[a] Valve settings were such that the first seven valves in the pass were fully open, the next seven were one-half open and the final two were one-quarter open. Measurements were taken in the early afternoon on each date and the air flow to 3rd and 4th passes was 5-6 MCFD.

[b] Locations referred to are as in the example:

Location P4-0.75

P4 refers to pass 4
0.75 refers to a point three quarters of the pass length from the beginning of the pass.

TABLE F10: DISSOLVED OXYGEN (mg/l) FOR SECTION 4, PASS 4[a]
EDMONTON SEWAGE TREATMENT PLANT JULY 15 - 21, 1974

	DATE				
Location	July 15	July 16	July 17	July 18	Average
P4-0.00	0.3	0.4	0.5	0.2	0.4
P4-0.25	0.3	0.5	0.6	0.5	0.5
P4-0.50	0.6	0.7	0.7	0.8	0.7
P4-0.75	1.5	1.8	1.2	1.4	1.5
P4-1.00	2.2	2.5	2.0	2.0	2.2

[a] Valve settings were such that all sixteen valves were fully open, measurements were taken in the early afternoon on each date and air flow to 3rd and 4th passes was 5-6 MCFD.

[b] Locations referred to are as in the example:

Location P4-0.75

P4 refers to pass 4
0.75 refers to a point three quarters of the pass length from the beginning of the pass.